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TAKING STOCK: THE ROLE OF NURSERY PRACTICE IN FOREST RENEWAL

Proceedings of a Symposium sponsored by the Ontario Ministry of Natural Resources and the Great Lakes Forestry Centre under the auspices of the Ontario Forestry Research Committee

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THE ROLE OF NURSERY PRACTICE IN FOREST RENEWAL

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and the
Great Lakes Forestry Centre
under the auspices of the
Ontario Forestry Research Committee
Kirkland Lake, Ontario
14-17 September 1987

C.R. SMITH and R.J. REFFLE, COCHAIRMEN

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FOREWORD

The symposium "Taking Stock: The Role of Nursery Practice in Forest Renewal" was held at Northern College of Applied Arts and Technology in Kirkland Lake, Ontario from 14 to 17 September, 1987. Sponsored by the newly formed Ontario Forestry Research Committee (OFRC), this was the 16th in a series of annual symposia previously held under the auspices of the Canada-Ontario Joint Forestry Research Committee. These symposia are designed to ensure effective communication of forest research results and innovative operational practices to forest managers and administrators.

The purpose of the symposium was to address both the requirements of and constraints on coniferous seedling production so as to promote among forest managers and nurserymen a better understanding of one another's problems and needs. In addition, it was hoped to promote more effective dialogue between grower and end user.

The meeting was attended by 197 delegates from the Ontario Ministry of Natural Resources (OMNR), the forest industry, private growers, the Canadian Forestry Service and other agencies. The symposium began with a historical review, by provincial forester K.A. Armson, of the role of nursery practice in forest renewal in Ontario. This was followed by an overview of the present situation in the province. Papers were presented that covered a full range of topics from seed collection and tree improvement to bare-root and container production cycles, innovations, definition and assessment of quality and a combined OMNR/Forest Management Agreement perspective on how well the field is being served. A field trip to the Swastika provincial bare-root nursery, three private nurseries and a planting stock comparison field trial gave delegates the opportunity to observe and discuss many of the concerns of nurserymen and end users. In poster sessions, additional information on recent research investigations and findings was presented. The symposium concluded with a lively and thought-provoking panel discussion on the question, "How well are we meeting artificial regeneration objectives, and what needs to be done to improve effectiveness of planting stock production and performance?"

The cochairmen extend their sincere thanks to program committee members J.B. Scarratt, Great Lakes Forestry Centre (GLFC) and C. Glerum, Ontario Tree Improvement and Forest Biomass Institute; to local OMNR organizers K. Gerber, C.K. Mahonen, K.M. Buck and E.M. Raitanen as well as to A. Citro, Forest Resources Branch; and to D.J. Kennington, GLFC (registration) and D. Ortiz, GLFC (publicity).

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TAKING STOCK: THE ROLE OF NURSERY PRACTICE IN FOREST RENEWAL

K.A. Armson
Provincial Forester
Ontario Ministry of Natural Resources
Toronto, Ontario

Abstract.--The history of nurseries in Ontario is reviewed and discussed under five developmental periods: the late 1800s to 1918, 1919 to 1945, 1946 to 1962, 1963 to 1980, and 1981 to the present. Nursery practices and development during each of these periods were significantly affected by a number of factors, some of them external to Ontario and Canada.

Résumé.--L'auteur passe en revue et examine l'histoire des pépinières en Ontario en fonction de cinq époques particulières : de la fin des années 1800 à 1918, de 1919 à 1945, de 1946 à 1962, de 1963 à 1980 et de 1981 à nos jours. Un certain nombre de facteurs, certains étrangers à l'Ontario et au Canada, ont beaucoup influé sur les méthodes utilisées en pépinière et sur leur évolution pendant chacune de ces périodes.

This symposium is part of a series initiated in 1973 by the former Canada-Ontario Joint Forestry Research Committee (COJFRC). It is the first to be held under the auspices of the Ontario Forestry Research Committee (OFRC), a committee of the Ontario Forestry Council (OFC), which has superseded all previous provincial forest research advisory bodies and is now the single agency in Ontario setting and advising about forest research priorities. The federal and Ontario governments, the forest industry, universities and forest managers are represented on OFRC.

Sowing seed and growing plants are ingrained traits in the human race. They have undoubtedly been fortified, during their evolution, by their link with human survival. The development of agriculture has always been associated with, or has resulted in, greater social stability. Hence, the growing of plants, from the point of view of society as a whole, represents "a good thing". The sowing of seed is the first step, and the tending of young plants represents a commitment that reflects concern for a crop that can be viewed only as a benefit to society.

Many of the common words associated with children are used in forestry — 'nursery' and 'rearing' in English, 'Baumschule' in German, and 'pépinière' in French. This close connection, in the public perception, between forest tree nurseries and other elements of society has been both a benefit and a detriment to forestry in the professional sense. It has been a benefit in that the growing of tree seedlings is like motherhood -- "a good thing". From politicians to payroll clerks, everyone is for it. Enthusiasm, however, can often outrun reality, especially when the production of seedlings is viewed as an end in itself. This misplaced enthusiasm is a source of unease to the professional forester who sees seedling production as a necessary component of the larger field, which is forestry itself. In Ontario and elsewhere in Canada, one would expect forestry practice, for the most part, to start with the regulation and manipulation of the largely natural existing forest and not with growing seedlings. The history of Ontario's forestry development, however, reflects the latter, not the former.

The development of nurseries and, to some degree, related practices, in Ontario has generally been in response to clearly identified needs. Although the introduction of tree nurseries was associated with the need to reforest agricultural 'wastelands' in southern

Ontario, the impetus came initially from fruit growers who were concerned about lack of protection for their fruit crops in southwestern Ontario. Their concerns were directed to the Ontario Agriculture College and, as a result, the first forest tree seedling nursery was established at Guelph in 1904. It was moved to St. Williams, which became the first provincial government nursery, in 1908, just three years after E.J. Zavitz, the forester who started the Guelph nursery, entered government service. The reforestation program and related nursery development in southern Ontario are to a large degree a reflection of Zavitz's influence and dedication.

Five broad periods of nursery development can be discerned in Ontario: the late 1800s to 1918, 1919 to 1945, 1946 to 1962, 1963 to 1980, and 1981 to the present. During these periods nursery practices were influenced by a number of developments on the international, national and provincial levels.

INTERNATIONAL DEVELOPMENTS

During World War I and World War II, nurseries and nursery practices either failed to develop or deteriorated because they were considered low priority and because professional and technical expertise was generally not available. However, in the aftermath of both wars, nurseries burgeoned. The most striking example of this burgeoning was the formation of the Forestry Commission in Great Britain and the establishment of tree nurseries on a grand scale. The greatest impact of this establishment was the development of a more scientific basis for nursery practices, especially in nursery soil management.

During the Great Depression of the 1930s, nursery development and practices languished. The economy was at a low ebb and so were government revenues. The only positive impact of this period on nurseries was that of the formation of the Civilian Conservation Corps (CCC) in the United States to employ young men in reforestation. The effect in Canada was indirect, by way of practices developed in the Lake States. An outcome of nursery development during this period was the publication of a regional compendium on practices by Stoeckeler and Jones (1957).

The years following World War II saw the scientific development of agronomy in North America. Many of the materials and practices in agriculture were applied in tree nurseries and resulted in major changes in the way nurseries were run. The most striking example was the use of herbicides to reduce hand or mechanical weeding.

NATIONAL DEVELOPMENTS

The major interest in forestry at the turn of the century resulted in the involvement of governments and a few forest companies in nurseries. The prime example of private sector involvement is that of the Laurentide Company in Quebec. Largely as a result of the efforts of its forester, Ellwood Wilson, this company developed both nurseries and plantations at Grand'mère in the 1920s. It was there that two recent forestry graduates from Toronto, Gordon Cosens and Robert Lyons, obtained early experience in reforestation which they made use of subsequently when they became senior vice presidents of Kimberly-Clark of Canada. They eventually established company nurseries at Moonbeam, near Kapuskasing, and at Longlac; the latter is still in operation.

The Canada Forestry Act of 1949 enabled the federal government to assist the provinces by funding various forestry practices and operations, among them the development of nurseries. A number of northern Ontario nurseries, including the Swastika nursery, became established in this way.

The latest initiative in support of tree nurseries in Ontario comes from the Canada-Ontario Forest Resource Development Agreement (1984-1989), which provides $133 million over a five-year period for intensive forestry practices. A significant portion of these funds has been allocated to nursery stock production.

PROVINCIAL DEVELOPMENTS

Some of the highlights of forestry development in Ontario are as follows:

- reforestation of southern Ontario's agricultural wastelands
- extension of reforestation to northern Ontario (1956)
- introduction of the Ontario tube seedling (1965-1966)
- introduction of Forest Management Agreements (FMAs) (1980)
- introduction of private container nurseries in northern Ontario (1981).

Obviously, many of these factors, international, national and provincial, are not mutually exclusive. For example, the impetus for establishing federal-provincial agreements in the late 1970s came from specific meetings such as the Canadian Forestry Association meeting in 1977 (Anon. 1978), and from significant publications such as *Forest Management in Canada* (Reed and Associates 1978). These reflected a great concern for the future forests of this country.

The production of bare-root tree seedlings in Ontario, from 1905 to the present, by the Ontario Ministry of Natural Resources (OMNR) and its predecessors, is shown in Figure 1. The initial surge in production, which culminated in the late 1930s, was related entirely to the planting of old agricultural land in southern Ontario, and in particular, to the establishment of Agreement Forests by counties and municipalities. Nursery soil management practices were generally in place until the early 1930s and, for the most part, were quite advanced. Stock consisted mostly of large bare-root transplants, and planting success was apparently high. From the 1930s to the mid-1950s both overall production and soil management practices were minimal, particularly in terms of organic matter, fertility and weed control. Demand for production increased gradually from 1946 to 1956, but much of this increase was attributable to stock coming from two new nurseries (Kemptville and Fort William), both established in 1946, and did not reflect an increase in overall per-unit productivity. It was a case of "over-capitalization" in an effort to increase supply, and this, in turn, reflected the paucity of nursery soil management practices.

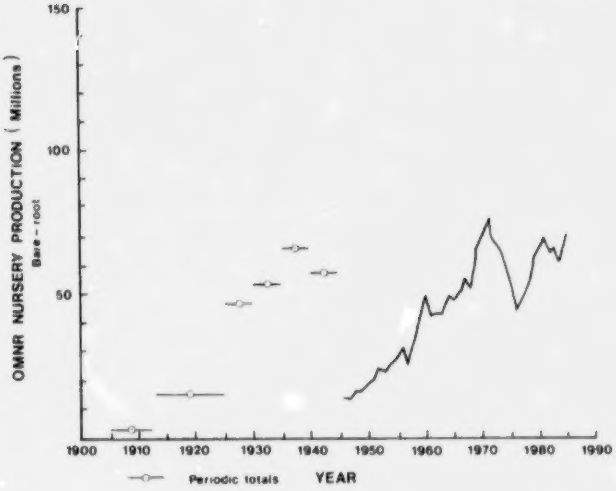

Figure 1. Bare-root tree seedling production from Ontario Ministry of Natural Resources nurseries, 1905-1986. Note that values for 1905-1912, 1913-1930, 1931-1935, 1036-1940, and 1941-1945 are totals.

Production numbers in themselves can be misleading since seedlings, in comparison with transplants, require less production space and time. However, seedling production during this period was minimal. The move to develop reforestation by planting in northern Ontario had two results: the establishment of new nurseries in the north (Table 1) and the move to produce a greater proportion of seedling stock for outplanting. Since current nursery practices were unable to meet the demand there was a major effort to improve nursery soil management by applying techniques and practices from other jurisdictions such as Great Britain, Scandinavia and the United States. Coupled with this was the use of field experimentation, particularly in soil fertility. Both of these initiatives were coordinated by R.D. Carman, a nursery soil specialist with the then Ontario Department of Lands and Forests, the predecessor of OMNR. My own involvement with nursery practices began in 1954, largely as a result of concern expressed by the Chief of the Division of Reforestation, G.H.U. Bayly, about the inadequacy of nursery practices. During this same period, Dr. R.E. Mullin of the Forest Research Staff was conducting extensive outplanting trials of nursery stock.

The new nurseries (Table 1) represent a mix of small and large operations. Of the six nurseries established, two have become major

Table 1. Ontario Ministry of Natural Resources forest tree nurseries, their year of establishment and current (1986) production.

Nursery	Year of Establishment	1986 Production	
		Bare-root	Containers
St. Williams	1908	6,400,000	-
Midhurst	1922	6,250,000	-
Orono	1922	5,000,000	-
Kemptville	1946	8,850,000	535,000
Thunder Bay (formerly Fort William)	1946	12,600,000	1,500,000
Thessalon	1955	1,400,000	4,250,000
Chapleau	1956	3,250,000	-
Gogama	1956	3,350,000	-
White River	1956	withdrawn from	production
Dryden	1958	4,250,000	1,350,000
Swastika	1958	18,000,000	-
	TOTAL:	69,350,000	7,635,000

facilities (Dryden and Swastika), one (White River) was closed, and one (Thessalon) has become primarily a producer of container stock. Although most of the new staff recruited for these nurseries had little previous experience, nurserymen's meetings were arranged periodically to assist in the transfer of knowledge and experience. There were many exciting new developments in the late 1950s and early 1960s. The techniques for producing 1½ + 1½ spruce were established by W.R. Bunting at this time. Incidentally, such stock was produced in Scotland at the turn of the century, a fact that illustrates the adage that there is nothing new under the sun. Fertilizer and irrigation regimes, together with a continuous and consistent documentation of stock, soils and practices, became a part of the provincial nursery system. These practices and documentation were included in a nursery publication (Armson and Carman 1961) that was revised and updated (Armson and Sadreika 1974) to include a section on container seedling production. Thus, the production system was largely established when the amendment to the Crown Timber Act of 1963 placed full responsibility for reforestation on Crown lands with Lands and Forests. The development of mechanical site preparation and the increased demand for planting stock could not yet be met by a system still devoted largely to conventional transplant stock. The Deputy Minister, F.A. MacDougall, sought to establish a program that could yield rapid results and be politically attractive; the result was the Ontario tube seedling program, which was based on years of persistent and relatively unsupported work by a forester with Lands and Forests, M. MacLean, and was organized by R.M. Dixon. The result was the "meccano set" greenhouses that sprouted in virtually every northern district beginning in 1965. Annual production in each of the years 1966 and 1967 was approximately 26 million seedlings.

Several features of the tube seedling program are worth reviewing, since they show clearly the problems that can occur when a major innovation is made in seedling production without reference to the context in which it is made. Tube seedling production was undertaken in districts without regard for the availability of expertise. Guidelines were established, but often the responsibility for growing the seedlings was treated as just another burden. Production was undertaken by Timber Management staff with little or no reference to the body of expertise on the nursery side of the department. The inevitable result was lack of interest by many staff and inadequate cultural practices. Although the three major pines — red pine (*Pinus resinosa* Ait.), white pine (*P. strobus* L.), and jack pine (*P. banksiana* Lamb.), as well as white spruce (*Picea glauca* [Moench] Voss) and black spruce (*P. mariana* [Mill.] B.S.P.), were grown, no serious attempt was made, by means of proper trials, to develop the cultural practices most appropriate to each. Indeed, in view of the nature of the container, only jack pine and, to a very limited extent, red pine, proved suitable for this type of production.

A second problem connected with the tube seedling program was that those who were implementing it failed to recognize that the success of outplanting, particularly of very small stock, depends very much on proper site preparation and subsequent tending.

Within four or five years the production of tube seedlings was virtually at a standstill except in a very few facilities where local interest and expertise, together with adequate site preparation, ensured planting success, mainly with jack pine. By 1972 production had reached a low of 2.9 million tube seedlings.

The program did result in innovations such as the use of the vacuum seeder and other mechanical devices, and greater attention was paid to the choice of appropriate sites and site preparation methods for container stock. These were both areas on which the Scandinavians concentrated when they developed container production and site preparation equipment in the late 1960s and 1970s.

Unfortunately, the failure of the program gave rise to a professional and technical skepticism about containers, especially the Ontario tube, and there was little or no progress in container seedling culture. In short, Ontario did not learn from its mistakes.

Container production remained minimal in the 1970s, although it more than doubled from 3 million seedlings in 1974 to nearly 8 million in 1979 (Table 2). The containers used were primarily paperpots and Spencer-Lemaire plugs; the use of tubes was minimal. During the same period the production of bare-root stock varied from 46 to 70 million seedlings, depending on the proportion of seedling and transplant production.

At this time, two factors related primarily to spruce production were of great concern. One was the quantity of viable seed sown to produce surviving 1+0 or 2+0 seedlings, especially black spruce. The other was 'cabbage heading', which resulted in seedlings with more that one leader and resulted in the consequent culling of such seedlings.

Table 2. Ontario Ministry of Natural Resources and private nursery production, 1969-1986 (millions of trees).

	OMNR		Private	
Year	Bare-root	Container	Container	Total
1969	62.6	6.0	---	68.6
1970	68.2	4.4	---	72.6
1971	76.6	5.1	---	81.7
1972	68.2	2.9	---	71.1
1973	65.4	3.4	---	68.8
1974	59.8	3.1	---	62.9
1975	50.9	5.3	---	56.2
1976	46.0	4.3	---	50.3
1977	48.3	5.5	---	53.8
1978	52.9	5.5	---	58.4
1979	61.5	7.9	---	69.4
1980	65.4	10.5	---	75.9
1981	69.5	14.0	---	83.5
1982	63.7	11.0	5.5	80.2
1983	67.5	14.7	25.3	107.5
1984	52.2	14.0	62.1	128.3
1985	70.3	8.7	70.5	149.5
1986	69.3	7.6	77.7	154.6

The problem had first been noted over the years at the Thunder Bay and Swastika nurseries. Uneven germination, largely as a result of changeable weather conditions in late spring and mortality resulting from fall and early spring frost heaving, were the major causes of spruce mortality in northern Ontario. The problem became particularly serious when black spruce seed production was reduced by spruce budworm infestations in the 1970s in the Northern Region. Attempts were made to minimize spruce seedling losses by spring sowing and the use of mulches, but the only satisfactory solution was to germinate and grow the spruce initially under semicontrolled conditions in plastic houses. This is now a well established practice (accelerated transplant production), and represents a solution to a problem that consists in changing the practice rather than modifying it.

The second problem, that of cabbage heading, has a long history of unsuccessful resolution. This problem has occurred sporadically, often virtually disappearing, only to recur some time later. Several scientists have attempted to determine its cause. Fertilizer crystals or pellets, high temperatures and insects have all been demonstrated, at one time or another, to cause multiple leaders, but none alone or even in combination seemed to account for the widespread and erratic occurrence of this phenomenon. Finally, R.E. Mullin posed a fundamental question. It was not "What causes cabbage heading?" but "Does cabbage heading or the presence of multiple leaders have any significant effect on outplanting survival or growth?" Mullin then set about experimentally to determine the answer. The result (Gross 1983, 1985; Paterson 1984) was clearly that multiple leaders have no deleterious effect on survival or growth of seedlings. Furthermore, seedlings with single leaders frequently develop multiple leaders after outplanting, and those that have them often revert to single-leader dominance.

This, as clearly as anything, illustrates the importance of viewing stock production objectively in relation to the purpose for which the stock is to be used. All cultural practices should be undertaken with a view to producing stock as economically and efficiently as possible to achieve a surviving plantation tree.

Cultural standards and practices must, if they are to be effective, reflect understanding of the seedling's biological processes and of how these can be affected not only by cultural practices but also by external conditions, which may be infrequent in occurrence or intensity. This is what might be termed the 'insurance' factor in seedling production. Farmers have the best understanding of this factor.

A recent example of practices that do not reflect such understanding is the death, in Thunder Bay this year, of seven million seedlings, a significant part of the crops of private growers and OMNR production facilities. This mass mortality was attributed to a combination of circumstances resulting in dead or inadequate root systems, which rendered the seedlings susceptible to severe moisture stress. Cultural practices and standards that focussed exclusively on the above-ground part of the seedlings undoubtedly contributed to the mortality.

Practices to maintain satisfactory soil fertility levels are now generally in use. One area in need of attention is the relation between water requirements and regulation of seedling growth. This is a complex relation because the nature of the soil rooting medium is often not uniform, growing facilities are different, depending on their location and weather conditions, and regimes that are suitable in one location may not be appropriate for the same crop in another location. In determining irrigation practices the grower must have a very clear understanding of the biological and physiological implications of such practices and of how their application will be affected by peat type, the nature of the container, the geometry of application, and so on.

If there are some principles that have been established over the more than 80 years during which tree seedlings have been grown on a large scale for outplanting in Ontario, they are as follows:

1. The biological requirements of the species must be thoroughly understood.

2. Cultural treatments should be understood, and applied in the light of a) the biological processes of the crop species, and b) the purposes for which the crop is being grown and the standards to be met.

3. The greater the uniformity and consistency in crop species, crop development, materials and treatments the greater the probability of producing a successful crop.

4. Anomalies in growth, especially when observed in experimental or trial projects, but also in routine production, should be rigorously analyzed and their cause sought.

5. Growing any crop involves building in buffers or 'insurance' practices that may seem unnecessary in any one growing season but may reduce the likelihood of major losses over the long term. Be sure you know what you are insuring against, and why and how you plan to do it.

6. You must never stop learning. Production must be efficient and cost-effective, from seed to established forest. Mistakes represent a major source of learning, but it is best to learn from the mistakes of others!

Finally, there is one aspect of nursery stock production that is, I suppose, a reflection of the nature of human society: changes in demand. Since the mid-1950s I have been impressed by the fact that if eastern North American nurseries were moving from transplant to seedling production, the western nurseries were usually going in the reverse direction. In Ontario, the shift from transplants to seedlings has gone through at least two cycles. The factors responsible for this shift are several: rapid increase in demand, which results in attempts to produce more seedlings, the greater land requirements and cost of transplants, and variable success in outplanting in relation to field conditions and practices. The impact on nursery practices and staff therefore can be very significant. The culture of 2+0 or 3+0 seedling stock entails quite different practices than that of transplant stock. Transplant production from OMNR nurseries increased from 9.6 million or 21% of the total bare-root production in 1976 to 37 million or 53% in 1986 (Table 3). The nearly eightfold increase in transplant production from northern nurseries without a major increase in land area has resulted from the use of greenhouse-grown seedlings for transplanting, combined with summer transplanting, a practice that has significantly reduced heavy losses, especially of black spruce in conventional seedbeds, and has shortened production time. In contrast, the production of transplants in southern Ontario has increased only minimally over the same period.

Table 3. Transplant production from Ontario Ministry of Natural Resources nurseries, 1976-1986 ('000) for northern and southern Ontario nurseries.

Year	Total transplants		Total transplant production	Transplant as a % of total bare-root production	Total bare-root production
	north	south			
1976	3,542	6,048	9,590	21	45,981
1977	6,579	5,599	12,178	25	48,212
1978	14,790	3,557	18,345	35	52,928
1979	13,445	3,557	19,307	31	61,453
1980	21,497	5,743	27,240	42	66,360
1981	22,090	7,243	29,333	42	69,448
1982	22,781	10,129	32,910	52	63,660
1983	25,256	10,909	36,165	54	67,473
1984	15,702	7,148	22,850	44	52,183
1985	30,892	7,525	38,417	55	70,343
1986	27,783	9,227	37,010	53	69,308

Another example of changes in requirements is reflected by the changing demand for species. Figure 2 shows the changes in production of white pine and red pine from 1934 to the present. Of particular note is the marked decline in white pine production from 1960 to the mid-1970s and its subsequent increase to the present, while red pine production has declined from 1970 to the present (Table 4). Several factors, including the nature of outplanting sites, may have contributed to these changes, but they also reflect, in my opinion, the recognition by many foresters that despite the initial negative appraisals of white pine planted in the 1950s and early 1960s because of losses to blister rust and deformation from weevil, subsequent appraisals showed that the surviving trees performed much better than expected. No doubt the fact that white pine became the arboreal emblem of the province in 1984 also gave production a boost.

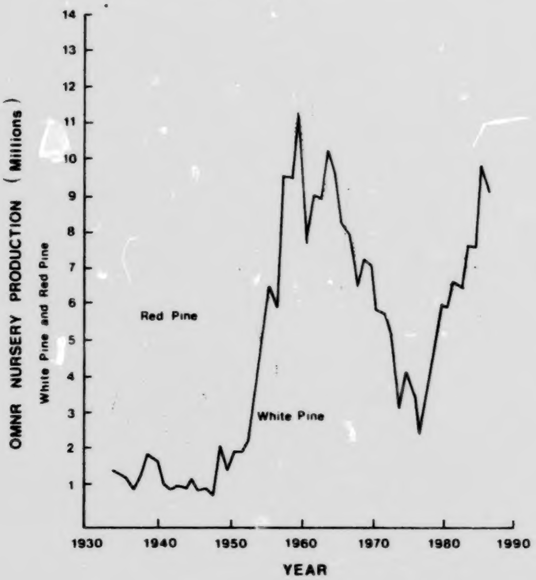

Figure 2. Ontario Ministry of Natural Resources production of white pine and red pine, 1934-1987 (millions).

Changes in production of other species, particularly those used in northern Ontario, have been even more dramatic. For example, jack pine production has increased from fewer than one million seedlings in the 1930s and 1940s to 50 million in 1986. White spruce production has increased from approximately one million in the 1930s to its present level of 17 million. The most striking increase in production has been that of black spruce. This species was not produced at all until the early 1950s, and initially only a few thousand seedlings were planted, but production was 57.8 million by 1986. It began to surpass white spruce production in the early 1980s and rapidly took the lead when it became the single largest crop in container production.

Table. 4. Production of white pine and red pine nursery stock ('000).

Year	White pine	Red pine	Year	White pine	Red pine
1934	1,392	3,143	1961	7,668	9,911
1935	1,328	3,622	1962	8,916	11,652
1936	1,249	2,637	1963	8,837	8,583
1937	922	3.106	1964	10,251	9,391
1938	1,274	2,850	1965	9,737	7,838
1939	1,931	4,368	1966	8,253	6,512
1940	1,692	4,003	1967	7,956	9.276
1941	1,094	3,050	1968	6,486	6,998
1942	837	1,963	1969	7,252	7,018
1943	966	1,411	1970	7,065	11,116
1944	887	1,755	1971	5,793	9,541
1945	1,153	2,966	1972	5,709	9,873
1946	864	3,289	1973	5,163	10,008
1947	866	3,612	1974	3,227	10,326
1948	711	3,022	1975	4,109	7,928
1949	2,044	4,920	1976	3,404	8,714
1950	1,368	5,461	1977	2,403	6,889
1951	1,945	6,458	1978	3,651	8,606
1952	1,866	6,977	1979	5,086	8,097
1953	2,164	5,975	1980	6,093	8,300
1954	4,023	5,601	1981	5,889	7,057
1955	4,873	6,372	1982	6,623	6,352
1956	6,455	6,372	1983	6,452	7,493
1957	5,879	4,093	1984	7,596	6,708
1958	9,592	6,355	1985	7,595	7,126
1959	9,560	6,785	1986	9,809	4,772
1960	11,395	11,572	1987	9,119	6,087

Such changes have necessitated different cultural treatments, and as we move toward greater selectivity in seed source and begin growing, on an operational basis, the products of tree improvement, even greater attention will have to be paid to stock production practices. That is one challenge that will continue. The other and equally important challenge is for us to review and assess stock production on a regular basis to ensure that we have a ready source of wood to sustain an industry that contributes so much to the economy of Ontario.

ACKNOWLEDGMENTS

I wish to express my appreciation to Messrs. R. Reffle and R. Crawford of the Forest Resources Branch, Ontario Ministry of

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PROVINCIAL OVERVIEW

R.J. Reffle
Supervisor, Stock Production Unit
Forest Resources Branch
Ontario Ministry of Natural Resources
Toronto, Ontario

Abstract.--Since 1979, container stock production in Ontario has increased 10 times as a result of the Forest Management Agreement program and the successful private growers' industry. Northern Ontario accounts for 83% of provincial production. Today, Ontario produces 160 million bare-root and container seedlings, or nearly one-quarter of the trees produced in Canada.

Résumé.--La production de plants en récipients en Ontario a décuplé depuis 1979 en raison du programme relatif à l'entente d'aménagement forestier et du succès remporté par l'industrie privée. Le nord de l'Ontario produit 83% des semis en récipients de la province. À l'heure actuelle, l'Ontario produit 160 millions de plants à racines nues et en récipients, soit près du quart de la production canadienne.

INTRODUCTION

In reviewing stock production in Ontario and Canada over the past several years, I note with interest that the increases in national figures and Ontario figures are almost identical. In 1979, Ontario produced 69 million trees (Tables 1 and 2) out of the national total of 311 million (Smyth 1980, Heeney 1982). In 1986, Ontario produced 155 million out of approximately 660 million. Ontario's portion of the national total over this period remained steady, between 22.5% and 23.5%.

Table 1. Stock production in Ontario from 1979 to 1986 (millions).

	Government		Private	
Year	Bare-root	Container	Container	Total
1979	61.5	7.9	-	69.4
1980	65.4	10.5	-	75.9
1981	69.5	14.0	-	83.5
1982	63.7	11.0	5.5	80.2
1983	67.5	14.7	25.3	107.5
1984	52.2	14.0	62.1	128.3
1985	70.3	8.7	70.5	149.5
1986	69.3	7.6	77.7	154.6

Other similarities are also evident. For example, the production of bare-root seedlings in Canada has remained almost static at 200 to 240 million. The same trend is true in Ontario. In 1979, more bare-root than container stock was produced nationally, but by 1986, this trend was reversed. Again, the situation in Ontario is identical.

However, there has been a tenfold increase in container stock production in Ontario over this period (1979-1986), whereas production in Canada as a whole has increased only four times.

Up to this point, Ontario has been the second largest producer of tree seedlings after British Columbia, but planned production in Quebec beyond 1987 will put Ontario in third place (Margolis 1987). However, since tree production is not an olympic event, it is more important to remember that, today, Ontario produces almost one tree in four in this country.

The province of Ontario is divided into eight administrative regions. Four of these, the Northwestern, North Central, Northeastern and Northern regions, form the subprovince of northern Ontario. The other four regions, the Southwestern, Central, Eastern and Algonquin, form the subprovince of southern Ontario.

Table 2. Stock production in Canada in 1979 and 1986 (millions).

	1979			1986		
	Bare-root	Container	Total	Bare-root	Container	Total
British Columbia	67	34	101	45	155	200
Prairie Provinces	21	23	44	35	35	70
Ontario	62	8	70	70	85	155
Quebec	31	1	32	65	90	155
Maritime Provinces	24	40	64	24	56	80
Total	205	106	311	239	421	660

In the two subprovinces the type of stock produced, the end-use of the product and, in some ways, the method of production, differ.

Northern Ontario contains approximately 87% of the provincial land base and, in 1986, produced 82% (127 million) of the provincial total of 155 million trees (Table 3). Ninety-nine percent of these northern-produced seedlings were used to reforest Crown lands.

In southern Ontario nearly half of the 27.5 million trees produced were sold to the public for reforestation of marginal farm lands, for windbreak establishment and for erosion control. An additional 30% or 8 million were utilized under wood production agreements between the Crown and landowners. Only 22% were planted on Crown land.

As you can see, most trees are planted on private land in southern Ontario, whereas the reverse is true in northern Ontario.

Table 3. Stock production in Ontario for 1986 by administrative region (millions).

Region	Bare-root	Container		Total
		OMNR	Private	
Northern	24.6	–	37.2	61.8
North Central	12.6	1.5	23.7	37.8
Northwestern	4.3	1.3	9.2	14.8
Northeastern	1.4	4.2	7.1	12.7
Subtotal (North)	42.9	7.0	77.2	127.1
Central	11.2	–	–	11.2
Southwestern	6.4	–	–	6.4
Eastern	8.8	.6	.5	9.9
Algonquin	–	–	–	–
Subtotal (South)	26.4	.6	.5	27.5
Total, Ontario	69.3	7.6	77.7	154.6

The seedlings produced in southern Ontario, 96% of which are from bare-root stock, represent 10 major species, including white pine (*Pinus strobus* L.) and red pine (*Pinus resinosa* Ait.) and an array of minor species such as oak (*Quercus* spp.), maple (*Acer* spp.), larch (*Larix* spp.) and ash (*Fraxinus* spp.).

However, in northern Ontario, only one seedling in three is bare root, with black spruce (*Picea mariana* [Mill.] B.S.P.) and white spruce (*P. glauca* [Moench] Voss) the principal species. The balance of northern Ontario production (66%) consists of container stock of mainly jack pine (*Pinus banksiana* Lamb.) and black spruce.

Of the trees grown in northern Ontario, the Northern Region produces 48%, the North Central 30%, the Northwestern 12% and the Northeastern 10% (Table 3).

The 62 million trees produced in the Northern Region in 1986 represent 40% of the provincial total and almost 10% of the national total. Of these 62 million trees, 40% are bare-root and 60% container stock.

As is obvious from these facts and figures, the major increase in stock production in Canada and especially Ontario has come in the form of container stock. Two factors have contributed to this phenomenal increase. The first is the Forest Management Agreement (FMA) system, which was introduced into Ontario in the late 1970s. Under this system, OMNR assumed responsibility for providing planting stock to all FMA holders. As a result there was a large and immediate demand for tree seedlings.

The second contributing factor was OMNR's decision in 1981 to privatize the production of container stock in order to meet this increase in demand. Today the private sector produces 50% of all trees grown in this province and 60% of all trees grown in northern Ontario. This increasing trend toward private production of container stock will, in all likelihood continue.

Other trends are also apparent when one reviews the past several years of planting stock production in this province. Although several of the northern nurseries have expanded their land base, the increase in transplant production by a factor of 8 has resulted in only a minimum total increase in bare-root production. This trend toward more transplants, primarily in the north, will continue and will be aided by the shift from field-grown transplantable material to greenhouse-produced material known as accelerated transplants. However, the total bare-root component will probably remain at the same level. Part of this strategy includes the conversion of bare-root jack pine to container jack pine stock where possible.

In summary, it is important to remember the following:

- Ontario produces almost one tree in four in Canada;
- 56% of Ontario production is container stock;
- 83% of Ontario production is in northern Ontario;
- Half of the trees produced in Ontario are from the private sector in the form of container stock;
- The Northern Region produces nearly 10% of the trees in this country;
- For the immediate future, bare-root stock production in Ontario should maintain its 1987 level at 70 million, with an increase in the transplant component; *if* total production should increase above the 160 million level, it will be in the container component produced primarily by the private sector.

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FOREST RENEWAL - A SHARED RESPONSIBILITY

J.B. Scarratt
Research Scientist
Canadian Forestry Service
Great Lakes Forestry Centre
Sault Ste. Marie, Ontario

Abstract.—The regeneration process is part of a forest management cycle that begins with harvesting and culminates in a mature, merchantable new stand. Regeneration is potentially the most risky phase of sustained yield forestry; if it is to be successful, each stage in the forest management cycle must be part of a comprehensive and fully integrated approach to forest renewal. A close working relationship between nurseryman and forest manager is especially important in this regard, for they share responsibility for both the implementation and the success of forest renewal programs. Greater efforts by both sides to understand each other's problems and constraints and better coordination of activities are essential to biological success and economic efficiency in meeting reforestation goals.

Résumé.— Le processus de régénération fait partie du cycle de l'aménagement forestier qui débute avec l'exploitation d'une forêt et se termine par l'obtention d'un nouveau peuplement exploitable et commercialisable. La régénération est probablement la phase la plus risquée d'un aménagement forestier avec production soutenue car chaque étape doit s'insérer dans une approche globale et pleinement intégrée au renouvellement des forêts si l'on veut assurer son succès. À cet égard, il est très important que les pépiniéristes et les aménagistes travaillent en étroite collaboration, car ils sont tous deux responsables de la mise en oeuvre et du succès des programmes de renouvellement des forêts. Ils doivent s'efforcer davantage de comprendre leurs problèmes et leurs contraintes réciproques et mieux coordonner leurs activités si nous voulons atteindre nos objectifs de reboisement d'une façon qui soit biologiquement réussie et économiquement rentable.

INTRODUCTION

To introduce the symposium topic and to put nursery production into context in relation to the broader issues involved in forest regeneration by planting, I was asked to give a brief overview of the forest renewal cycle. I do not intend to give a step by step account of the various activities that are involved in establishing a new crop on cut-over forest land, for these will already be familiar to most of you. Rather, I would like to use this opportunity to promote the concept that forest renewal is very much a team effort, and that only through the coordinated efforts of all participants can we expect to succeed in meeting reforestation goals with any degree of confidence. Acceptance of this premise and implementation of a more holistic approach become increasingly important as we endeavor to move toward more intensive forest management and face greater public accountability, both economic and environmental, for forestry activities.

To a large degree, and partly for historical reasons, forestry operations in Canada typically have become compartmentalized into separate functions, with specialized groups dealing with harvesting, seedling production, forest management, forest protection, etc. Frequently there are further levels of compartmentalization within these different operating areas. Because of the scale of most forestry undertakings in this country and the long crop rotations involved, such functional specialization has obvious organizational benefits in concentrating effort and expertise. However, it also involves certain risks. The principal danger is that, through concentration on their own day to day problems, "specialist groups" have a strong tendency to develop tunnel vision with respect to their own function, thereby losing sight of the common goal and becoming essentially self-serving. Because of the pressure to get the job done, the needs and problems of the other "players" are often forgotten, and soon we have separate groups defining and pursuing their own independent goals. Collectively, we must be alert to the problem and strive to ensure that we all remain on the same course, irrespective of our function.

The basic message I want to leave with you today is that, whether we are nurserymen, regeneration foresters or forest managers, we must learn to work together for the common good. We are all contributors to the larger goal of sustained yield forestry, and as such must recognize that our separate goals are inextricably interlinked. We all know that well worn truism about the weakest link in the chain and all that, so I do not need to repeat it here. However, it is true that we risk failure if any stage of the forest regeneration/forest management process is faulty or if it is not in tune with the common goal.

THE FOREST RENEWAL CYCLE

With something in the order of 800,000 ha of forest land being harvested in Canada each year (Anon. 1987), forest renewal is one of the most important problems facing the forest manager today. There is now a broad recognition of the need for prompt, successful regeneration in order to ensure a continuing supply of wood products for the future, and most provincial administrations have increased their reforestation efforts dramatically in recent years to meet this challenge. However, as reforestation programs have expanded, it has become increasingly apparent that the regeneration process is frequently the costliest and potentially the riskiest phase of sustained yield forestry. The cost of regeneration is principally an investment in the future crop, even though there may be subsidiary objectives such as maintenance of wildlife habitat, recreation, social goals, etc. If that investment is to pay off and if we are to maintain a viable forest industry, it is clearly desirable that we facilitate the rapid establishment of a vigorous new crop by all means at our disposal.

You will hear a great deal over the next few days about the various biological, environmental, and operational factors that govern nursery practice, affect planting stock performance and plantation establishment, and ultimately determine the success or failure of a regeneration operation. But there is another level of constraint that can also profoundly influence our efforts. This lies in our whole approach to forest renewal. All too often we fail to remember, or fail to respond to, the fact that the regeneration process is part of a cycle of events that begins with harvesting and culminates in a mature, merchantable new stand (the "common goal"). By ignoring this fact we greatly increase the risk of regeneration failure, with all that this implies in terms of sustained yield. If forest renewal is to be biologically successful and economically efficient, every stage in the cycle must be part of a comprehensive and fully integrated management program. In this sense, we all share responsibility for the ultimate success or failure of forest renewal.

At the simplest level, the forest renewal cycle for artificial regeneration by planting can be broken down into seven primary phases, of which four constitute the actual regeneration process (Fig. 1). Traditionally, the regeneration forester has come into the picture only after harvesting is completed, and has had to contend with whatever site conditions were left by these operations. In many cases harvesting has left post-harvest conditions that have substantially increased the difficulties and costs of regeneration, or have otherwise reduced the effectiveness of regeneration efforts. This is not to blame the forest industry, but simply to point out our past failure to recognize the importance of coordinating harvesting methods, in terms of their effect and timing, with reforestation operations.

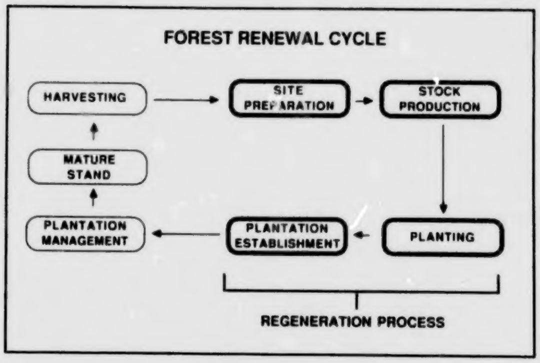

Figure 1. Basic model for forest renewal by planting.

For example, both method and intensity of harvesting can have a major influence on the success of reforestation as a result of their effects on the environmental conditions to which seedlings are exposed. Harvesting has the potential for creating the greatest changes in seedling environment (Greaves et al. 1978) and should be so planned that it will create conditions that interfere least with seedling establishment. Thus, the amount of slash left on the ground will be much less with full-tree logging than with tree-length systems (Zasada 1971). This in turn will increase the net area available for planting and improve the likelihood of achieving a well stocked stand, although we must be cognizant of the fact that slash removal may be counterproductive in terms of nutrient conservation on certain sites. The removal of undesirable or unmerchantable trees at harvesting, though uneconomical from a purely commercial viewpoint, may also increase the area available for planting, and at the same time facilitate mechanized reforestation operations. Furthermore, the removal of undesirable hardwood seed sources may be beneficial in preventing their reproduction and in reducing subsequent brush competition. On the other hand, site treatment, whether by logging or by site preparation, can be too intensive. Thus, severe soil disturbance may exacerbate weed problems by improving conditions for the germination and sprouting of hardwoods (Wood and Campbell 1988). At the other extreme, there may be situations in which it is desirable to retain vegetative cover or an overstorey to protect regeneration from adverse environmental conditions (e.g., frost).

These are just a few examples to illustrate the importance of our adopting a holistic approach to forest renewal and management, and of the need for harvesting to be considered an integral part of the renewal process. Likewise, in planning nursery and reforestation operations, we have to realize that an established plantation is not an end in itself, but merely one of several intermediate destinations along the road toward a mature, merchantable stand. After establishment, a plantation needs to be tended, managed and protected to maximize growth and yield and minimize rotation length. But here, as in other phases of the renewal cycle, there are no simple rules or relationships. Post-establishment stand management options will be strongly influenced by the results of regeneration operations and local site conditions as, ultimately, will the yield of a stand.

While one of the main objectives of the Ontario Forest Management Agreements (FMAs) is to coordinate the planning and implementation processes for harvesting, regeneration and forest management (Tollinsky 1985), it is clear that one of the greatest potential barriers to operational integration is the tendency to tunnel vision referred to in my opening remarks. FMAs provide us with an opportunity to change the face of forestry in Ontario, but we must strive continually to keep the common goal in sight if the forest renewal cycle is to be managed effectively.

REGENERATION CHAINS

The basic model for the forest renewal cycle (Fig. 1) can be elaborated in any number of ways to illustrate the different management options that are possible depending upon the various inputs to the system. For example, Figure 2 indicates some of the more significant inputs that might be expected to influence planting stock performance during the establishment phase of artificial regeneration. This diagram was originally developed to demonstrate that stock character, as determined by nursery cultural practices, is but one of a number of factors affecting plantation establishment, and to point out that nursery production objectives must always be responsive to feedback that is based on field experience. In fact, this feedback loop makes it clear that the various factors influencing planting stock performance are by no means independent. Rather, they are very highly interdependent.

It is evident from the foregoing that, for any given situation, there may be several possible alternative pathways (regeneration chains) for achieving forest renewal objectives, the feasibility and practicability of which will depend on biological, operational and economic considerations. Clearly, there is often no "best way" to do a job, and a decision to undertake a particular function at a given level in one area (e.g., site preparation or chemical weed control) frequently allows a tradeoff in another area (e.g., type and grade of planting stock). Other examples are discussed by Wood and Campbell (1988) in a later presentation in this volume.

A hypothetical regeneration chain, from harvesting to second-generation pulpwood stand, is illustrated in Figure 3. This simple model shows some of the alternative treatments that may have to be considered by the forester who is developing a plan for managing and artificially regenerating a particular site. It is important to realize that the optimum pathway may vary from site to site, and that a decision to adopt a particular strategy at any given point in the chain (e.g., containerized versus bare-root planting stock) usually cannot be made in isolation

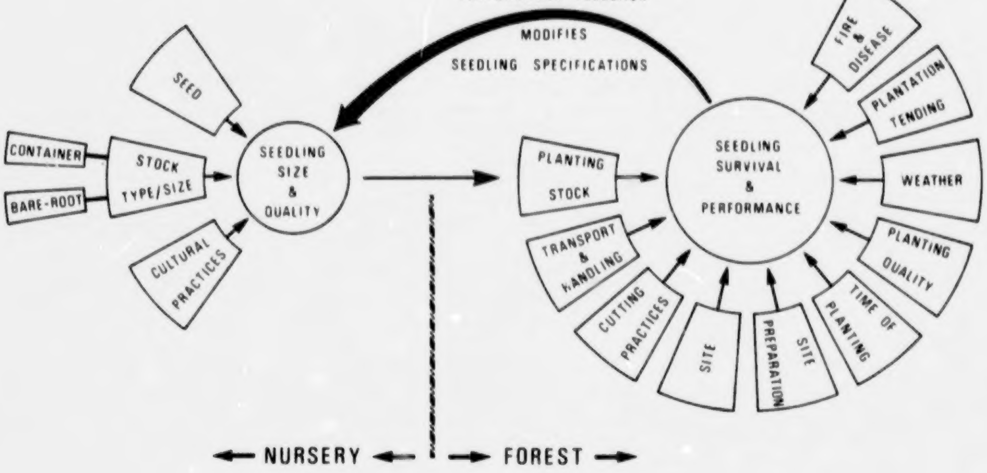
PERFORMANCE FEEDBACK
MODIFIES
SEEDLING SPECIFICATIONS
SEED
CONTAINER
STOCK TYPE/SIZE
BARE-ROOT
CULTURAL PRACTICES
SEEDLING SIZE & QUALITY
PLANTING STOCK
TRANSPORT & HANDLING
CUTTING PRACTICES
SITE
SITE PREPARATION
TIME OF PLANTING
PLANTING QUALITY
WEATHER
PLANTATION TENDING
FIRE & DISEASE
SEEDLING SURVIVAL & PERFORMANCE
NURSERY
FOREST

Figure 2. Factors influencing planting stock performance during the establishment phase, with emphasis on the nursery component.

from other components of the chain. We should keep this clearly in mind as we discuss nursery objectives and practices over the next two days.

Theoretically, there is no reason we could not develop, in full detail, a decision-model for the entire forest renewal cycle from harvesting through to a mature new stand. However, not only would such a model be exceedingly complex, but our current knowledge of the various interrelationships involved, particularly the costs and benefits of different alternatives, is quite inadequate for such a purpose (Räsänen 1988). Although regeneration practices have been studied for many years, and have generated much biological and economic information, there is a strong need to synthesize the knowledge currently available in order to understand the regeneration process as a whole (Payandeh 1988a). In consequence, biological and economic models for forest regeneration are still in their infancy (Räsänen 1988), although rapid advances are being made in the modeling of individual segments of the forest renewal cycle (Ek et al. 1988; Hämäläinen et al. 1985; Parviainen and Lappi 1983; Payandeh 1988a, 1988b).

My purpose in introducing the modeling concept is to emphasize the complex interactions and dependencies that, in total, ultimately determine the success or failure of the regeneration process. Modeling also serves to reinforce the message that, as loggers, nurserymen or forester managers, we are but part of a larger picture, and that errors of omission or judgment on our part could result in higher than necessary costs, and lead to anything from minor loss of productivity to serious economic loss in terms of growth potential. Rarely will good practices in one area make up for errors or deficiencies in another. Only by carefully coordinating our best efforts at all stages in the regeneration/forest management chain can we hope to maximize the benefits of investments in forestry.

THE NURSERY-FIELD INTERFACE

In closing, I would like to say a few words about the roles of the nursery manager and regeneration forester in the overall forest renewal cycle.

The nurseryman's basic function is to produce planting stock whose morphological and physiological condition meets the requirements for establishing new plantations of rapidly growing trees. The role of the forest manager is to provide conditions at the planting site, including handling practices, that will facilitate rapid establishment and encourage this planting stock to perform as well as the site will allow. We know that no single nursery product or regeneration strategy is suitable

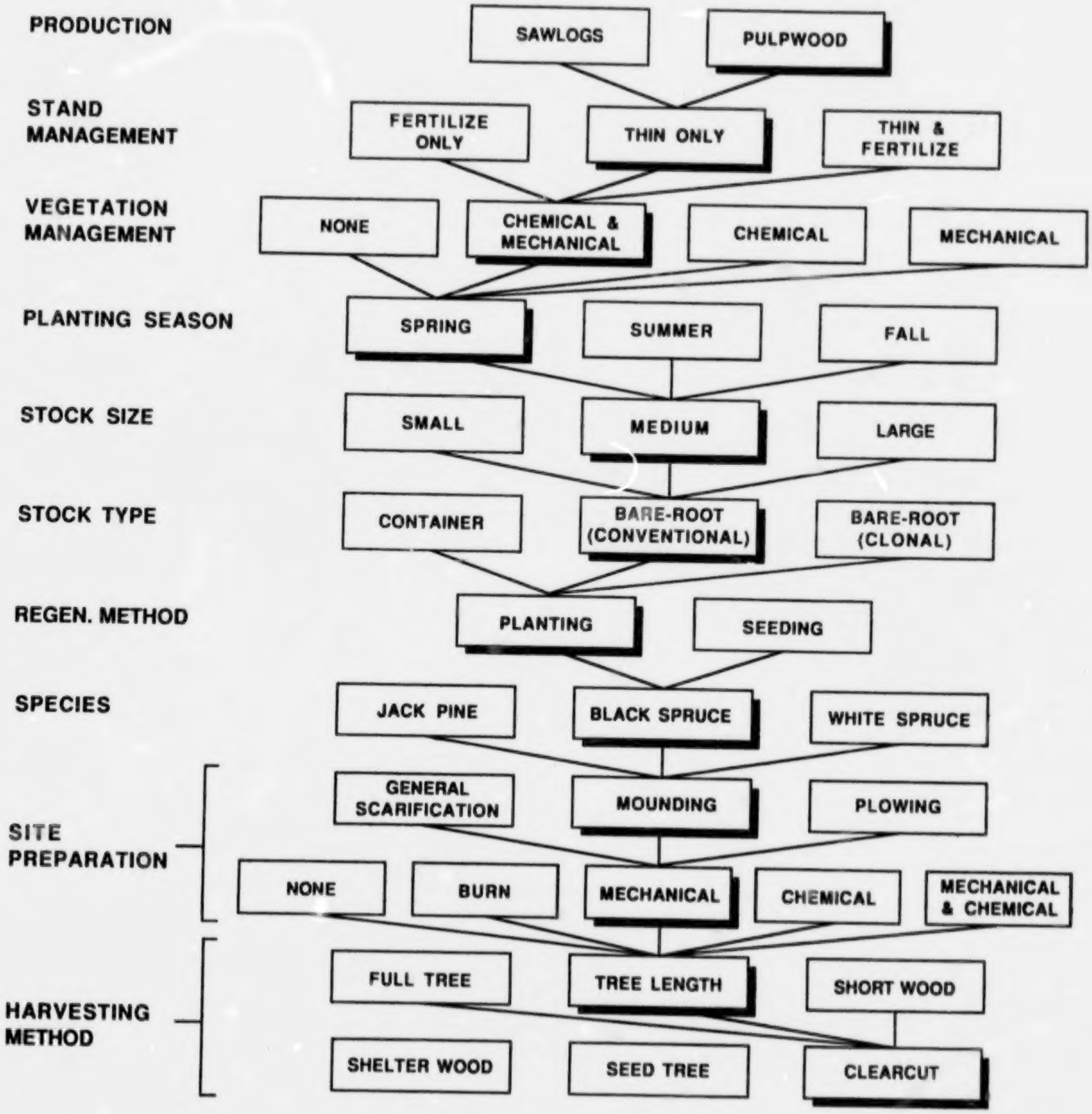
PRODUCTION
SAWLOGS
PULPWOOD
STAND MANAGEMENT
FERTILIZE ONLY
THIN ONLY
THIN & FERTILIZE
VEGETATION MANAGEMENT
NONE
CHEMICAL & MECHANICAL
CHEMICAL
MECHANICAL
PLANTING SEASON
SPRING
SUMMER
FALL
STOCK SIZE
SMALL
MEDIUM
LARGE
STOCK TYPE
CONTAINER
BARE-ROOT (CONVENTIONAL)
BARE-ROOT (CLONAL)
REGEN. METHOD
PLANTING
SEEDING
SPECIES
JACK PINE
BLACK SPRUCE
WHITE SPRUCE
SITE PREPARATION
GENERAL SCARIFICATION
MOUNDING
PLOWING
NONE
BURN
MECHANICAL
CHEMICAL
MECHANICAL & CHEMICAL
HARVESTING METHOD
FULL TREE
TREE LENGTH
SHORT WOOD
SHELTER WOOD
SEED TREE
CLEARCUT

Figure 3. Example of a forest renewal chain, from clearcutting (bottom) to new pulpwood stand (top), through hypothetical treatment alternatives.

for all sites, or even at all times on the same site. Consequently, nursery manager and forester must work together to ensure that seedling characteristics and regeneration methods are in harmony with each other, both biologically and operationally, for the specific site being regenerated. Only in this way can we hope to achieve fast, effective plantation establishment. It is that simple!

Unfortunately, this ideal has not been achieved in practice. The nursery/field relationship has long been a prime example of tunnel vision, with the two sides often becoming so wrapped up in their own problems and functions that they lose sight of the fact that they are both working towards the same goal. As a result, each side tends to operate within boundaries that, for operational or other reasons, it sets for itself. This has led to what I call the "nursery gate syndrome", in which the nursery, in the absence of specific guidelines or feedback from field staff, produces stock on the basis of its own perception of needs, and in which field operations and goals are frequently out of synchronization with those of the nursery. In these circumstances, it is perhaps not surprising that each side is liable to blame the other if planting stock fails to perform well after planting.

While it may seem rather harsh judgment, it often appears that the end result is one of the lesser concerns in the process of getting the job done. Consequently, situations arise in which the least-cost principle, applied to seedling production, overrides (or ignores) considerations of effective plantation establishment, or in which other nursery constraints are allowed to dictate seedling specifications rather than the needs of the sites on which that stock will be planted. In the field, we still see actively growing, overwintered jack pine container stock planted as late as July, contrary to advice from the nurseries, mainly because bare-root planting takes precedence in the spring. This occurs despite the fact that such containerized seedlings undergo greatly intensified physiological stress in comparison with those planted early, and may suffer high mortality as a result. Similarly, shipping and handling practices often are governed more by operational convenience than by the biological needs of the planting stock.

These few examples epitomize the lack of mutual understanding that often seems to pervade the relationship between nursery and field staff, and is, I believe, a major obstacle to the implementation of a successful regeneration strategy. Much of the problem undoubtedly arises from our general failure to adopt a holistic approach to forest renewal and the lack of clear management policies for the regeneration process. At the working level, however, it seems that the situation is most commonly attributable to an ignorance of the problems and restrictions, both biological and operational, under which the other party has to operate. This cannot continue. The complex nature of the regeneration process demands close and sympathetic cooperation between nurseryman and forest manager if the system is to work effectively. To summarize cogent remarks by Edgren (1980), "nursery manager and forester ...... need each other's input, ... cannot function separately or independently ...... (and) must know each other's problems for this team to function efficiently".

If forest renewal operations are to be successful, it is essential that both nurseryman and forester recognize their shared responsibility and adopt a team approach to the question of regeneration and plantation establishment. This requires that both sides develop a much greater commitment to the concept of a common goal. In practice, this boils down to better communications, a willingness to see each other's viewpoint, and a full understanding of one's own place in the scheme of things. That is the challenge of this meeting.

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QUALITY STOCK THROUGH QUALITY SEED: THE ROLE OF TREE IMPROVEMENT

R.M. Rauter
Supervisor[1]

and

J.V. Hood
Forest Geneticist

Ontario Ministry of Natural Resources
Tree Seed and Forest Genetics Unit
Toronto, Ontario

Abstract.—The success of new forest plantations will depend, in part, on the quality of seed used for artificial regeneration. A good-quality seedling begins with a seed that is in good physiological condition, and this is achieved through proper attention to collection, storage and handling practices. We can obtain even better-quality trees if the genetic potential of our seed is increased, as is possible through a sound tree improvement program. Tree improvement can be implemented at several levels of intensity, with corresponding increases in the genetic gain possible. Although seed with greater genetic potential will also benefit stock growers, greater attention to identification and tracking of seedlots and stock will be necessary. Intensive tree improvement programs require a significant initial investment, but the possible benefits more than justify the cost.

Résumé.—La réussite des nouvelles plantations forestières dépendra en partie de la qualité des semences utilisées pour réaliser la régénération artificielle. Un semis de bonne qualité ne peut être obtenu qu'à partir d'une graine saine et en bon état; il faut donc accorder une attention particulière à la récolte, à l'entreposage et au traitement des semences. Nous pouvons obtenir des arbres d'une qualité encore plus grande en augmentant le potentiel génétique des semences grâce à un programme bien pensé d'amélioration générale des arbres. Le gain génétique éventuel sera fonction de l'intensité de sélection. Il est certain que les producteurs tireront avantage de semences à potentiel génétique supérieur; il faudra par ailleurs identifier et déterminer avec plus de soin l'origine et la destination des lots de semences et du matériel. Les programmes intensifs d'amélioration générale des arbres exigent une mise de fonds considérable qui est plus que compensée par les bénéfices qu'ils laissent présager.

INTRODUCTION

Successful artificial regeneration of our forest lands depends on many factors, and two of the most important are seed quantity and seed quality. The issue of quantity is obvious: without an adequate seed supply, no regeneration will occur, either naturally or artificially. However, seed quality plays an equally important role and, in fact, quality may be the chief issue in artificial regeneration since, in natural regeneration, quantity can often compensate for lack of quality.

The effect of seed quality may be seen throughout the entire process of forest renewal. The success of direct seeding is in part dependent on the quality of the seed used. The quality of planting stock produced in nurseries and greenhouses is related to seed quality. Finally, the productivity of the new forest can be greatly affected by seed quality.

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[1] Present title and address: Executive Assistant, Ontario Forest Industries Association, 130 Adelaide St. West, Toronto, Ont. M5H 3P5

For the purpose of this paper, we will subdivide the discussion of seed quality into two areas, *physiological quality* and *genetic quality*. We define physiological quality as the set of physical characteristics that affects such parameters as germination rate and germinative capacity. The *potential* to produce a better-than-average tree, under non-limiting conditions, we define as genetic quality. Although in practice it is not entirely possible to separate physiology and genetics, this approach will better indicate the manner in which forest management practices and, in particular, *tree improvement*, can affect seed quality and, ultimately, forest productivity.

OBTAINING GOOD-QUALITY SEED

Good-quality seed must be in a sound physiological state by the time it is ready for sowing. The condition of the cones also plays a role in the efficiency of the entire seed acquisition process.

Good Seed Years

Seeds should be collected only in good flowering years when there is an abundance of pollen to fertilize the female flowers. This means better seed set in each cone collected, and translates into lower collection costs per seed collected. Also, in good flowering years, there are better opportunities for cross-pollination and less chance of self-pollination (selfing). Selfing generally produces lower seed sets as well as seed that may have reduced growth potential. Reduced growth potential can mean that the nurseryman will experience greater difficulty in growing a seedling that meets height and diameter standards and the field forester will be forced into longer rotations to obtain harvestable trees.

Cone and Seed Maturation

Ensuring that the cones and seed have sufficiently matured on the tree prior to collection reduces the chance of case-hardening among cones following collection, and consequently the process of seed extraction becomes very difficult. Seed extracted from immature cones has low germinative capacity and poor storage characteristics. When cones and seed are mature, the seed is in a better physiological state, i.e., is easier to extract from the cones, has a higher germinative capacity, and stores better and longer.

Proper Storage and Handling of Cones

The manner in which cones are collected, handled and stored greatly affects the physiological condition of the seed. Cones must be properly air-dried prior to shipping so that molding, which reduces the germinative capacity of the seed, does not occur. Conditions that may cause the cones to overheat should be avoided, since higher temperatures during seed development can adversely affect germination rates.

Seed Storage

Seed must be stored at the proper temperature and humidity. Improper conditions will lead to a progressive and rapid deterioration of germination performance in each succeeding year. Movement of seed in and out of storage will also shorten its shelf-life. When excessive quantities of seed are requested from the seed plant, and the left-over seed is returned, this returned seed will have reduced germination and germinative energy.

Advantages of Collecting Good-Quality Seed and Cones

The advantages of collecting good-quality seed and cones are as follows:

1) seed is easier to extract

2) there is a higher number of full seeds per cone

3) the unit cost per viable seed for collection and storage is lower

4) the seed has higher viability and germinative capacity

5) the seed stores better and longer

6) there is greater likelihood of uniform germination.

OBTAINING BETTER-QUALITY SEED

The discussion above focused primarily on the topic of ensuring that the seed used for artificial regeneration is in good physiological condition. This will generally lead to better-quality planting stock. There are even greater potential benefits, however, if the stock used to plant the new forest has the capacity to outproduce the original forest. *Tree improvement* can provide this opportunity by increasing the genetic quality of the seed used.

To set goals and objectives and to provide strategic plans for implementing tree improvement programs, the Ontario Ministry of Natural Resources (OMNR) prepared a *Tree Improvement Master Plan for Ontario* (TIMP).

The goals, as presented in TIMP, are as follows:

1) genetic quality of all new forests at least equal to that of the forests they replace, and a modest increase in genetic quality through appropriate seed source control
2) an increase in the production and quality of new forests of major commercially important species by planting genetically improved trees on the most productive sites.

Two programs, differing in management intensity and resource requirements, have been implemented to achieve these goals. The *base program* is intended to provide an interim supply of seed that is both appropriate to the site and, if possible, genetically improved to a limited degree. This is achieved by restricting the movement of planting stock and by limiting seed collection to specific stands.

The *intensive program* is intended to provide seed with substantially enhanced genetic potential. This objective is achieved through a rigorous selection, testing and breeding program. The resulting seed for regeneration will be produced in special-purpose plantations called *seed orchards*, whose sole, but crucial, function is to produce genetically improved seed.

Seed Source

Ensuring that seed comes from the proper seed source is a factor affecting quality of growth in our production plantations. Generally the local seed sources are the best, since the local populations have withstood generations of natural selection in the local environment. Foreign seed sources should not be used unless they have been tested in the environment in which they are to be artificially regenerated as they may not be able to cope with changes in day-length, rainfall, frost-free period, and soil types.

Stand Quality

Collecting seed from good-quality stands is important since the offspring may exhibit characteristics similar to those of their parents. For example, if the stand has trees with poor stem form and high branch angle, a proportion of the offspring will exhibit these same undesirable traits.

The OMNR base tree improvement program recognizes several different types of special stands for seed collection. Among them are the seed collection area (SCA) and the seed production area (SPA). Although there are a number of differences in selecting and managing the two areas, the one difference pertinent to this discussion is the level of genetic improvement possible. There is little management in an SCA, but an SPA stand may be selectively thinned to leave only the very best trees as seed producers, thereby making possible some genetic gains.

Seed Orchards

As described above, a seed orchard is a specially designed plantation for the production of genetically improved seed. In the initial phases of a tree improvement program, trees with desired characteristics are selected from natural stands; criteria for selection are based on the desired end-product. For example, Christmas tree growers would select for needle retention and needle color, whereas lumber producers would be interested in straight stems and small branches.

To establish a seed orchard, either open-pollinated seed or branch cuttings are collected from selected trees. The seed may be sown and the resulting seedlings planted in a *seedling seed orchard*. Alternatively, the branch cuttings may be grafted onto seedling rootstock and the grafts planted in a *clonal seed orchard*. At the same time, or within a short period after orchard establishment, genetic tests are undertaken to determine the extent to which superiority of a given selected tree is hereditary. When test results are available, the seed orchard is selectively thinned, and only individuals with proven superior genetic capacity to produce seed for artificial regeneration are left.

Seed Orchard Program

The following table shows the status of the OMNR seed orchard program since 1980 for the four major species, as well as the total number of , hectares required to satisfy demands..

Priority species to date	Production orchards, total area (ha)	
	Required	Established
Black spruce	315	118
Jack pine	208	144
White spruce	147	67
White pine	118	47
Totals	788	376

Managing Seed Quality and Quantity

The cost of treating natural stands or unimproved plantations to induce better cone crops can seldom be justified. More frequently, treating SPAs to increase cone and seed production is a tenable management option. In contrast, it is necessary to manage seed orchards for maximum productivity in order to obtain early returns from the large initial capital investment. Two common seed orchard treatments are irrigation and fertilization. Irrigation systems are expensive and consideration must be given to the anticipated increase in quality and productivity based on species, site and environment. Cover crops can assist the manager in managing water loss better in an orchard.

Different fertilizer regimes are used for the establishment and the flower production phase of an orchard. Fertilization in the early years can shorten the time from planting to seed production. Once an orchard is of flowering size and age, fertilization can increase the frequency of crops and quantity of cones produced, and assist in producing larger quantities of better developed seed.

Flower induction is an area that has received increased emphasis in the past few years. We can encourage early flowering through physiological manipulation of the tree with drought stresses, fertilization, root and crown pruning, and hormones. This can be done in the usual soil-based orchards, but can be better controlled in breeding halls. Breeding halls can be used for small production programs as is done for European birch in Finland, for the production of limited seed for the purpose of growing seedlings for genetic tests, or for the use of parent donor stock in clonal forestry programs in which the stock is used to produce cuttings. The latter two are under way in Ontario.

EFFECT OF IMPROVED SEED ON STOCK PRODUCTION

Seed from a well managed, fully productiv capacity and should germinate more uniformly. The stock should achieve the required standards more quickly and easily.

With identified seed sources growers will be handling increased numbers of seedlots and smaller numbers of seeds per lot, and they must have the flexibility to deal with these smaller seedlots. They must also keep detailed records and carefully monitor stock identification in the greenhouse.

CLONAL FORESTRY

Clonal forestry enables us to expand limited numbers of genetically improved seed through mass production by rooting cuttings. Each individual produced from a parent plant is genetically identical to the parent. This has been common practice for many years in the poplar program, but has only recently been practicable with our conifer species. There are many advantages to clonal forestry, among them the following:

a) it stretches small quantities of desired seedlots

b) it makes propagation of some species easier

c) it is cost-effective for the propagation of expensive cultivars, e.g., species hybrids or pest-resistant clones

d) it captures *all* of the favorable genetic variation (Sexual reproduction, i.e., seed, can capture only a portion.)

e) it matches specific clones to specific sites

f) it ensures greater uniformity in production plantations

g) it reduces time from selection to production deployment.

Challenges to the growers include managing donor stock to produce large quantities of cuttings that are conditioned to root well, and lowering the cost of production through mechanization of the labor-intensive process. It is important that these methods of stock production be available to us; for the forest industry to remain competitive in the world market, we must use all means available to grow better trees faster.

ECONOMICS OF TREE IMPROVEMENT

Tree improvement is capital intensive, but the dividends are good. They can be obtained, however, only when programs are properly planned and implemented, when they are done in concert with good site selection and site preparation, and when good stock is produced for the artificial regeneration program. Tree improvement pays only when seed is efficiently used to grow the stock. Time is also a critical factor in a tree improvement program. If the time involved in planting improved stock can be shortened at any step in the process, the returns on the investments will be increased.

CONCLUSIONS

The forest industries in this province face many challenges in the future that will have an impact on their competitive abilities in world markets. Growing plantations that produce more wood of a quality equal to or better than current quality, and in shorter rotations, are two of those challenges. Paying proper attention to seeds, the ultimate beginnings of those plantations, will significantly improve the industries' chances of remaining competitive in the future.

BARE-ROOT PRODUCTION CYCLE

K.H. Reese
Nursery Superintendent
Ontario Ministry of Natural Resources
Midhurst, Ontario

Abstract.--*Bare-root stock production requires two to four years from the time of seeding to the time of shipping. As conventional production takes place out of doors, it is subject to severe weather conditions and prolonged exposure to insects and diseases. Many factors are beyond the control of the nurseryman and affect the reliability of the system in meeting targets. The relatively long planning and production cycle can appear to be inflexible in the face of changing demands made by the planter.*

Résumé.--*La production de plants à racines nues demande de deux à quatre ans, à partir de l'ensemencement jusqu'au moment de l'expédition. La production classique s'effectue en plein air. Elle est donc soumise à des conditions climatiques rigoureuses et à une exposition prolongée aux insectes et aux maladies. Le pépiniériste est dans l'impossibilité de contrôler un bon nombre de facteurs, et c'est pourquoi le système n'atteint pas toujours les objectifs visés. Le cycle de planification et de production relativement long peut sembler immuable face aux variations de la demande émanant du producteur.*

INTRODUCTION

Nursery production can be defined as the growing of planting stock from a propagule to the physical size required by the customer and in a physiological condition that will enable satisfactory growth when it is planted.

The propagule may consist of a seed, a cutting or a graft. Nursery staff treat the seed to enable it to germinate, put a root on the graft or the cutting, and then culture each to the appropriate size.

No matter what type of propagule is used, and what its genetic quality may be, the cost of each product will be the same. The seed from an open-grown pasture pine will cost the same to grow as the seed from an orchard cross, and a graft of a green Colorado spruce will be the same as that of an intensely blue Hoopsi variety. The facilities and the cultural steps for each will be the same and hence the costs will not vary.

This paper will deal with the growing of planting stock from seed by means of the traditional open-field or out-of-doors techniques. During this symposium you will be made aware of how the bare-root system is using container technology for those species which are difficult to grow in traditional nurseries. Greenhouses are being used to overcome the high losses in the first growing year and to produce bare-root seedlings for transplanting, and in some situations, containerized seedlings are being used for transplanting.

What are the characteristics of the bare-root system? The lead time required to produce a plantable seedling is the length of the nursery rotation plus one year for planning. A 2+2 spruce, therefore, takes 5 years, provided that seed is in place. These rotations mean long periods of exposure to weather, disease, insects, etc. For the year 1 seedling, the germination period, the first few weeks after germination, and the frost-heaving period just before the snow comes are particularly critical. These long rotations are frustrating for the planter as he attempts to adapt to changes in the environment and in his own requirements, and meets with resistance from the bare-root system. Another characteristic of the conventional bare-root system is the high risk involved because of unpredictable losses between seeding and shipping. For example, with spruce we sow 8-15 seeds to ship one tree in spite of irrigation, shades and mulches.

SPECIFICATIONS

Some of the current specifications are based on nursery crops before harvesting, while others are based on packaged seedlings. Reese and Sadreika (1979) described what the nurseries can grow, and, by means of photographs and tables, showed the variation that can be expected in a crop of seedlings of various age classes or sizes and species. Their data were derived from fall plant samples before any culling or grading had been done. Cultural treatments are usually developed by nurserymen to deal with trees of average size.

The best description of ship stock is found in Day (1985) and is based on packaged seedlings. Day's manual is being used by nurseries to rate the morphological quality of bare-root seedlings as they are being shipped from the nurseries. The minimum quality that is acceptable is stated in culling rules that use height, diameter, root size and physical condition to describe seedlings.

In practice the nurseries can cull to different grades for different cutovers. We provide one grade for private land, one for Crown land and one for Forest Management Agreement projects. The grading is controlled basically by the size of seedling grown by the nursery and by what one is prepared to pay for grading out these special sizes. In developing specifications for planting stock we have to keep in mind that we are growing for mass plantings and not for individual specimens. We plant four to five times the number of trees required to provide a harvest and our primary criteria have to be the general size, condition and vigor of the crop, not of the individual seedling. From a nurseryman's perspective we are barking up the wrong tree, at our present level of spruce reforestation, when we ask the nursery for larger seedlings. We can always grow larger and larger trees but the costs increase significantly and the capacity of the nursery system decreases with longer rotations. At this stage, communication between planters and nurserymen is poor, and the latter often lack sufficient information to perform their work properly, particularly when site preparation for some working groups is so inadequate and tending is so primitive. Although we are making significant strides in site preparation, follow-up ground treatments are very difficult and inhibit many tending operations that would aid juvenile growth.

LAND PREPARATION STAGE

The first stage in production is to translate the production target into the total area required and to select the compartments in which seeding and transplanting will take place. The basic texture and general fertility level separate pine land from spruce land and seedbeds from transplant beds. Because of the vulnerability of black spruce to frost heaving, the requirements for black and white spruce differ. Each nursery has a wide range of soil and fertility conditions and the matching of production targets to the 80-120 compartments requires considerable discussion and recollection of previous conditions. Once this basic selection is made, soil preparation begins. Annual soil analysis at Glendon Hall guides the detailed additions of lime or sulfur for pH control, peat for organic content and fertilizers for P, K, Ca, Mg, etc. Chemicals for disease and insect control are also added. Because of this process, as the seeding date draws closer the resistance of the nurseryman increases if the planter attempts to change his demands for stock, even though it may be reasoned that there is no need for the nurseryman to fuss when there is no seed yet in the ground.

SEEDING

We can seed either in the spring or in the fall. Most conifer species, if spring seeded, require stratification for 60 days. On average we get better germination in the spring because there is less seedbed deterioration as a result of weathering. Since spring-sown seed germinates later, more tending at germination time is required because of the increasing temperatures.

The amount of seed required to produce a tree varies considerably with the species. At Midhurst, for jack pine, we sow approximately four seeds to ship a tree, while at the other extreme, for black spruce transplants we sow about 15 viable seeds for this purpose. These factors are based on 5-year average survival rates, and contain a disaster allowance. This planned germination is rarely achieved in practice because of the averaging.

If germination is below the average, the nursery will, from this early production stage, forecast a shortage at time of shipping. This forecast will be reported in the annual inventory report. When shipping is forecasted 2-3 years in advance, shortages can be coordinated and, if necessary, other parts of the stock production system can be brought into play.

The predictability of germination is critical to target achievement and also to various aspects of quality, particularly root collar diameter and the amount of root present at lifting time. The germination rate is based on tests done at Angus to estimate the percentage of viable seed. We find occasionally that the number obtained in Angus tests a much higher germination than we achieved and we are unable to determine why. This usually happens with old seed and it happened two years ago with 3100-3200 white spruce from Chapleau. The reason seemed to be that although the Angus test data were confirmed, the seed did not have the vigor to germinate through the layer of covering sand and hydramulch. The predicted germination rate, on the basis of Angus data, was 80%, but germination at the nursery was only 19%.

The quality of seed in transplant production is not important as long as its performance is predictable. In seedling production seed quality is more important. In the south, we are switching back from transplants to seedlings for some purposes so that the wheel has gone full circle. In seedling stock production, seedbed density is critical. Precision seeders, seed sizing, and uniform germination all play a part in seedling stock production; hence, more seed must be collected to permit more screening and better cleaning at the seed plant.

It is to be hoped, as well, that the performance of the numbered collections is being monitored, particularly if repeated collections from the same area are planned, for when one sees the seedlots growing side by side, it is obvious that some are performing quite poorly.

TRANSPLANTING

The purpose of transplanting is to produce a heavier seedling with an improved top:root ratio. Transplanting ensures more space for the seedling to grow and enables it to achieve a greater diameter and more weight. The act of planting also encourages a finer, heavier root system. Pine is planted in the spring, as is spruce for a 2+2 rotation. Spruce for a 1.5+1.5 rotation is planted in the summer. Transplanting is labor-intensive and increases the cost of production by 25-40%.

Transplants are physically attractive trees and are more reliable than seedlings for outplanting. They also grow better if competing vegetation permits. Although we are growing a large percentage of transplant stock, these heavier and costlier seedlings are not essential to satisfactory growth on the easier sites if site preparation and control of competition are carried out properly.

The recent use of repeated root pruning and root wrenching throughout the growing season in years 2 and 3 has greatly increased the amount of root on seedling stock and significantly improved the top:root ratio.

TENDING

Tending operations have two purposes. Some are considered essential to the crop, while others are insurance. The principles of tending, however, are the same for trees as for any other crop, i.e., to provide water, food, space and protection.

At Midhurst, we have one employee who measures soil moisture to determine the best rate of irrigation. We have 7-day coverage, and a minimum of two staff members engaged in the irrigation procedure. Water improves the survival of the seedlings and, if used sensitively, can help regulate growth.

Fertilization involves as many as eight applications of granular nitrogen, which we may supplement with several applications of liquid fertilizer. We are particularly concerned about year 1 growth because, if we have small 1+0 trees, we will ship a small grade in year 3. We will also have handling and packaging problems if the trees are too large in year 3.

The use of herbicides is essential. We use eight of these, although only two are registered specifically for nursery use. We use one or two tractors continuously to spray weeds. A field of 1+0 seedlings may receive up to eight treatments of herbicides, some for 6- to 8-week control, some for scorch kills, and some for path cleanup. Two staff members check regularly for weeds, supplementing the Operations Manager's regular checking.

I emphasize tending because I think that our young plantations are badly tended, and I recommend the use of herbicides because they are essential, and in most cases are underutilized or not used at all.

HARVESTING

With bare-root stock, the period between lifting and replanting is a very critical one during which seedlings can be easily damaged. Handling is important and the rules are very simple: keep the trees cool and the plants--particularly the roots--moist. Refrigeration has become an important tool in the distribution system as we try to maintain food reserves and root regeneration capacity. I remember Bob Mullin saying that only extreme damage leads to the death of seedlings: usually damage results in reduced growth, and this often goes unnoticed.

The inventory of shipping stock is first undertaken in June as a forecast based on counts made the previous year, and is usually updated visually. It is done again in August as part of the annual inventory, on the basis of counts just taken. At Midhurst there can be a number of differences between the two inventories. Damage due to root rot does not show up until later in August after the summer heat, and in red pine it can be serious. Other differences arise when, during lifting, we do not control the culling closely enough and fail to do it according to the original plan. At Midhurst lifting is completed in three weeks. It takes the lifters at least three days to get into a routine, and by then a million trees have been lifted. Wet soils can result in more root damage than was allowed for, and consequently, there can be underruns. The fall of 1986 was very wet at Midhurst. There were numerous complaints that the bags were too heavy because of the large amounts of soil they contained. Stock in parts of some fields could not be lifted because of lack of traction and severe stripping of the fine roots; these seedlings were not picked until the spring. It is important to recognize problems early enough and to rectify them so that the planter will not be faced with unexpected situations.

FUTURE DIRECTIONS

In the future, the changes in the bare-root system that will affect planters most profoundly are those related to the use of mechanical lifters for shipping. At nurseries in high-transplant regimes, better quality stock can be lifted and packaged directly from the harvesting equipment, with only an estimated count per package. Piecework planters will therefore have to be paid by the number of hectares planted rather than by total trees planted. If block planting could be adopted in some areas, the need for small bundles of 25 trees apiece could be avoided. The less handling, the more quickly the seedlings are packaged and the less exposure there is to drying conditions.

In the growing phase, one important innovation is the use of greenhouses in the production of seedlings for transplanting. This is because of the remarkable uniformity of the size of stock and because production will be more reliable for meeting targets. When the automated transplanters are functioning, it is hoped that the cost of transplant production will decrease.

In the past few years some very important strides have been made in the use of root pruning to improve root development on seedling stock, and for some species and some uses it may be possible to convert 3-year-old transplant stock to 3+0 seedlings.

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CONTAINER PRODUCTION CYCLE

R.J. Reffle
Supervisor, Stock Production Unit
Forest Resources Branch
Ontario Ministry of Natural Resources
Toronto, Ontario

Abstract.--Standard container stock production operations such as preparation of the growing medium, seeding and growing are the responsibility of the growers, primarily. The role of the end-users is to provide a description of the stock they require and to assist in the selection of the appropriate container. The growers must then formulate the appropriate growing schedule in order to deliver the contracted product in the proper condition at the right time. The majority of problems common to both groups can be resolved by effective communication.

Résumé.--Les opérations classiques de production de plants en contenants, comme la préparation du milieu d'élevage, l'ensemencement et la culture, sont la responsabilité des producteurs, principalement. Le rôle des utilisateurs consiste à fournir une description du matériel dont ils ont besoin et à aider à la sélection du contenant approprié. Les producteurs doivent ensuite établir le calendrier de culture qui convient afin de fournir le produit demandé dans les conditions et au moment voulus. La plupart des problèmes communs aux deux groupes peuvent être solutionnés par une bonne communication.

In this paper I shall attempt to provide an overview of the container stock production cycle in Ontario in order to point out to field staff the areas in which compromise or change is not possible.

The greenhouse container nursery offers a degree of control over seedling physiology that the outdoor bare-root nursery cannot match (Tinus 1982). Trees are produced in greenhouses in order to optimize conditions and minimize time frames. However, the more sophisticated and complex the equipment and the more condensed the time frame, the greater the risk of error.

In Ontario the most widely used container is the 408 paperpot. Of the 85.4 million containers produced in 1986, 72.3 million or 85% were 408 paperpots, 10.6 million or 12% were Spencer Lemaires and the remaining 2.5 million or 3% were multipots (OMNR, unpublished data).

A long list of decisions has led us to this present mix of container types. Field staff must be made aware that there is no ideal container but there is usually one that is best for a given production and planting situation. The best size and type can be determined by analyzing cost, survival and growth (Tinus and McDonald 1979). Unfortunately, in the past the decision to change from one container to another was based on opinion rather than experience. Any change in container type must include an evaluation of the ability of the tree production industry to adapt to new growing techniques, to changes in total volume output and, usually, to a higher unit cost.

There are several aspects of container planting over which field staff have no control. They are entirely in the hands of the grower.

PEAT

Two of the most significant purchases a container grower makes are the container and the growing medium.

Growing medium is the material that fills the containers and performs the same function for the seedling as soil does in the field (Tinus and McDonald 1979). In Ontario peat-vermiculite mixes are the most common medium.

Peat sold commercially varies in quality, and this can cause problems in nurseries in which seedlings are to be grown consistently to specific dimensions within a certain period of time (Hellum 1975).

The quality and consistency of peat continue to pose considerable problems (Millson 1986). Growers must modify their cultural practices to compensate for the variability of the growing medium. It is not simply a matter of "what worked last year will work this year."

Once the growing medium is prepared the containers must be filled. Trays are filled mainly on automatic filling lines, and a certain amount of manual touch-up is usually required. All aspects of production, including growing medium, trays, containers, equipment and labor, are involved in the process, and the task must be performed over a short period with little or no error.

Ideally, the filled containers will be moved immediately to the seeding operation.

SEED AND SEEDING

The main objective of the filling and seeding operation is to ensure that the entire crop starts germination at the same time.

Seed for container stock should be the cleanest available, and should have high viability and the ability to germinate rapidly. If a seedlot has low viability, more than one seed is placed in a cavity and thinning and transplanting are necessary to ensure one tree per cavity. Both operations are costly and in most cases are unpredictable.

MULCH

Once the cavities are sown, they are covered with a coarse-textured material to protect the seed from drying and excessively high temperatures. This covering also inhibits weed and moss growth and prevents the seed from being dislodged. However, it must not interfere with the germination process. If the mulch or grit is too thick it may impede seedling germination; if too thin it will not achieve its purpose.

PHASES OF GROWTH

The first phase of growth is germination. The objective is to achieve quick germination so as to get the seedlings off to an even start. This evenness will help reduce most of the variability in a crop and will pay dividends during the growing, inventory and shipping phases. The most critical variables during germination are temperature and moisture availability.

The second phase of growth consists of juvenile development and exponential growth. During this period, the grower follows a specified growing schedule while monitoring greenhouse equipment and recording activities. He should observe the crop daily for disease, insects, growth and color. This period will vary in length depending on species and size of seedling required.

The third and final phase is the development of stem caliper (diameter) and cold hardening. This period begins when most of the seedlings have reached an acceptable height. The objective is to cause the formation of apical buds. Once adequate stem diameter, bud and root development have been achieved, cold hardening must begin. The purpose of cold hardening is to prepare the seedlings for a harsh environment and avoid damage.

The aforementioned operations, from filling the containers to seeding, growing and hardening, are the responsibility of the grower, and field staff should have little or no part in them.

The major areas in which field demands cause problems for the nursery manager are the selection of a container type and the size of seedling required. Logically, one should dictate the other. Unfortunately, in some cases, stock standards are established after a container system is selected and it becomes a never-ending struggle to achieve these standards in a totally inadequate container. It gradually becomes a case of trying to put "two pounds of meat into a one pound bag." Also, the time a container is required for planting is as important as the standards and the container selection. Once the key questions "What do you want?" and "When do you want it?" are answered, a comprehensive growing schedule can be formulated.

In summary, field staff have a major impact on the description of the stock required and they assist in the selection of the appropriate container to match required seedling parameters. The grower must formulate a growing schedule in order to deliver the appropriate product in the right condition at the right time. However, the most important factor in the production cycle is communication between the grower and the end-user. I firmly believe that good communication can go a long way toward helping us to solve the majority of our common problems.

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TECHNICULTURE TRANSPLANTS:
AN INNOVATION IN PLANTING STOCK PRODUCTION

R.A. Klapprat
Nursery Superintendent
Thunder Bay Forest Nursery
Ontario Ministry of Natural Resources
Thunder Bay, Ontario

Abstract.--The Castle and Cooke Techniculture greenhouse transplant system is described. The intended goal in introducing the system at the Thunder Bay Forest Nursery was to improve reliability in achieving production targets. Both experience and observations during tests permitted expansion of the list of advantages of the system to include: improved reliability in achieving targets, increased production capacity of the nursery, better seed utilization, improved stock quality, and improved operating efficiency.

Résumé.--L'auteur décrit la méthode de transplantation en serre Techniculture de Castle et Cooke. La pépinière forestière de Thunder Bay a eu recours à cette technique afin de s'assurer d'atteindre régulièrement ses objectifs de production. L'expérience et les observations faites au cours des essais ont révélé que cette technique comporte de nombreux avantages: plus grande certitude d'atteindre ses objectifs de production, augmentation de la capacité de production de la pépinière, meilleure utilisation des semences, amélioration de la qualité du matériel et rendement accru.

This paper outlines the greenhouse transplants system in operation at the Ontario Ministry of Natural Resources (OMNR) forest nursery in Thunder Bay.

As background I should like to refer to changes that occurred in the early 1970s. At that time it was shown that transplant-type planting stock was surviving, growing and, in general, performing better than the seedling-type stock usually requested. Requests for this "new", preferred stock constituted a challenge for the nurseries. In the production of seedling-type stock it was not difficult to overseed by a few hundred percent in order to ensure that targets were met. When transplants became the preferred stock type, it was not feasible to overplant because the cost of production was much greater.

There are two stages in growing transplant stock: the seedling stage and the transplant stage. It is the seedling stage that causes growers the most difficulty. So many factors are involved in the production of suitable seedbeds, such as soil type, fertility, and moisture; organic content; seed placement; control of erosion, weeds, insects, pathogens, birds and rodents; provision of shades, top dressing, and irrigation; and control of wind, low temperature and frost heaving. To compensate for the toll taken by these various elements, we have been planting up to 12 seeds to produce one shippable tree. Even so, we are often caught short when these factors combine adversely in unforseen ways.

To overcome these difficulties, it seemed sensible to grow the seedlings under more controlled conditions; hence, we decided to use greenhouses. Next, we had to determine the most appropriate type of container. We tried raised beds; large, deep and shallow boxes; large cavities and small cavities; broadcast seeded trays and regular container stock trays. We tried various growing media as well, including mineral soil, peat, sand, mixtures of peat and sand, perlite, vermiculite and mixtures of all of the above. We also tried synthetic media such as rock wool, compressed fiber and various plastics and polymers. From these attempts, it became apparent that some container types and growing media could provide more advantages than simply greenhouse reliability. Just when we thought we had investigated all available options, a product came to our attention that featured a tray which provided for very high density in the greenhouse and a medium that lent itself to mechanized handling. When small-scale trials with this product showed promise, we began larger semi-operational production.

The patent for this product, known as the Techniculture system, is held by the Castle and Cooke Company of Hawaii. The system is used extensively by their subsidiary, the Bud Antle Corporation of California, for lettuce production. Because the use of this system for forestry does not conflict with the vegetable production of that company we were able to obtain it for our purposes.

By using the Techniculture system, we quickly learned that the desired reliability could be achieved by making use of greenhouse climate controls and the accurate inventory counts that are possible.

Besides achieving reliability, we were able to increase our production capacity. Instead of growing our crop in 3 years as with the traditional 1½+1½ stock, we could now grow it in only 2 years after the 10-week greenhouse phase. In addition, since we have moved the seedbeds indoors, we are vacating fields that could produce more ship stock.

We were also able to achieve better seed utilization. Instead of the ratio of 12 seeds per shippable tree that we had to seed for in the past, we were able to reduce the figure to 3 seeds per shippable tree. This is proving to be an even greater advantage as we begin to use improved seed.

Another unforeseen benefit of the system is improved stock quality. We achieve this by avoiding J-root or hockey stick distortions induced in traditional stock types by the Holland transplanter. We are achieving continuity in growth after transplanting actively growing trees since there is no "stress" period from pruning or exposure of roots. By transplanting early in the spring, we are growing our stock in synchrony with nature, thereby permitting better bud development and hardiness. By planting seedlings early in the season, we achieve good anchoring and avoid the S-shaped stem resulting from frost heaving. In addition, our clients tell us that the dense mass of roots and favorable shoot: root ratio mean a more desirable product.

The final benefit is improved efficiency. We achieve this through reduced seed requirements, production costs of the transplants, and transplanting costs; faster, more efficient harvesting rates; and fewer culls, with the possibility of a bed-run harvest.

CULTURAL AND OPERATIONAL TECHNIQUES

- We begin with a tray that already contains the soil medium, which consists of about 90% peat and is bound together with a polymer material, called *rubber soil* .

- Pallets of the trays are brought to the greenhouse door and seeding is done right in the greenhouse. Because all seeds are placed in a similar micro-environment (a cavity within the plug that is 0.8 cm in diameter and 0.25 cm in depth), very even germination results.

- After germination the seedlings are grown much as regular container stock, although precision in applications is much more crucial, mainly because of the very small volume of medium in each cavity.

- We are at present growing three crops a year. The first or current crop is grown from mid-March until late May, acclimatized briefly, then transplanted in the nursery in early June. The second crop is grown from late May/early June until August, when it is moved to the shade area where it remains until October. The third crop is grown from August until October, when dormancy is induced. Both the second and third crops are overwintered in refrigerated storage, where they remain until May, when they are transplanted in the nursery. There is also potential for a fourth crop, which can be grown from January until March; however, further investigation is required before production of this fourth crop becomes feasible.

Since a single crop in a single greenhouse that is 9.14 m x 43.9 m can produce 1¼ million seedlings, three crops in three greenhouses will produce all of our transplant stock.

During the development phases of the system the 10-week-old seedlings in their rubber soil plugs were transplanted in nursery compartments with the Holland transplanter by means of a small clip improvised to support the plug. This was a very slow procedure, in which the machine moves at 2.5 - 3.0 m a minute. The California company using this system had developed a mechanized transplanter. However, it was designed to plant at spacings of about 25 cm between plants and 50 cm between rows. By modifying their patented mechanism, we were able to build an eight-row, self-propelled, automatic transplanter that can plant at 6 cm between plants and 16 cm between rows. This machine can move down the field at about 3.2 km/hr and can plant nearly 200,000 plants/hr. It is manned by a driver and two feeders who merely plant the trays in slides in the mechanism and remove the empties as they emerge from the bottom. The machine does the rest.

OVERWINTER STORAGE OF NURSERY STOCK

S.J. Colombo
Research Scientist
and
G.D. Racey[1]
Biometrician
Ontario Tree Improvement and Forest Biomass Institute
Ontario Ministry of Natural Resources
Maple, Ontario

Abstract.--Overwinter frozen storage offers numerous logistical and biological advantages associated with an assured supply of dormant stock for spring planting. Operational systems for frozen storage are now in place for bare-root stock and are being developed for container stock. The electrical impedance technique for determining readiness for storage of bare-root stock is now being implemented operationally. For container stock, the existing frost hardiness testing procedures can be used to predict readiness for storage.

Résumé.--La conservation hivernale dans un entrepôt réfrigéré offre de nombreux avantages sur les plans logistique et biologique, garantissant un approvisionnement en matériel de reproduction à l'état de dormance lors des travaux de plantation du primtemps. Il existe maintenant des systèmes opérationnels d'entreposage au froid des plants à racines nues et de tels systèmes sont actuellement mis au point pour les plants en récipients. La technique de l'impédance électrique, qui permet de déterminer si les plants à racines nues sont prêts à être entreposés, est maintenant opérationnelle. Dans le cas des plants en récipients, les méthodes actuelles d'essai de la résistance au froid peuvent servir à la même fin.

INTRODUCTION

Each year, Ontario ships approximately 160 million tree seedlings for planting, of which 130 million are overwintered. Only about 15% of this stock (approximately 25 million bare-root seedlings) is kept in frozen storage over winter. In the case of bare-root stock, lack of available storage space and, until recently, lack of reliable criteria for determining when seedlings are sufficiently hardened off for lifting are the reasons for this small percentage. In the case of container stock, it is only in the past 5 years that the number of container seedlings produced and the stock losses associated with outdoor overwintering have increased to the point at which overwinter frozen storage has become a priority; hence, storage facilities are not available and the testing of container storage procedures is only now in progress.

Overwinter frozen storage of nursery stock offers many advantages over the traditional practice of overwintering stock outside in both bare-root and container seedling nurseries. Logistically, it is advantageous to store stock during the winter because it (1) allows an early, accurate inventory of the total number of shippable trees, (2) reduces the heavy spring workload by fall lifting and grading, (3) permits shipping of stock for snow cache storage, and (4) increases the practicability of container stock. The use of overwinter frozen stored stock also offers a number of advantages in stock quality: (1) overwinter seedling losses that are due to shoot desiccation, root freezing, disease and rodents can be controlled, (2) seedlings can be kept in storage throughout the planting season so that they maintain the high stress resistance typifying dormant stock, and (3) the quality of multiple-cropped container stock can be maximized by greater use of warm temperatures during hardening before storage.

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[1] Present title and address: Integrated Resource Management Specialist, Northwestern Ontario Forest Technology Development Unit, Thunder Bay, Ontario

The purpose of this paper is to review existing systems of overwintering for bare-root and container stock and to describe methods of determining when stock is sufficiently hardy to be placed in storage.

BARE-ROOT STOCK

Seedlings in bare-root nurseries rely on growth cessation and increasingly cold temperatures in late summer and early autumn to promote hardiness before severe winter weather sets in. Two-year-old red pine *(Pinus resinosa* Ait.) and white spruce *(Picea glauca* [Moench] Voss) seedlings at the Midhurst Tree Nursery, for example, initiate terminal buds very shortly after the current year's buds have begun to break in late May, and shoot growth is complete by the end of June (Colombo, unpublished data). Consequently, seedlings have well developed buds and can respond to cold night temperatures and mild frosts, which may begin in early to mid-August, so as to develop high levels of hardiness.

Snow cover is important for overwintering stock outside. Lack of snow often results in winter damage, whereby the exposed portion of the shoot or the needles on it die as a result of desiccation. Stock overwintered outside is lifted in spring, graded, packaged and placed in cool (above freezing) storage for up to 8 weeks before planting, although the preferred storage period is less than 3 weeks.

Successful overwinter frozen storage of bare-root stock hinges on accurate prediction of the time at which seedlings are ready to be lifted for storage. Readiness for storage is closely related to dormancy status (Hocking and Nyland 1971, Racey 1984), and its timing can vary from year to year and between species and geographical locations of nurseries (Racey 1984). Three techniques have been used at various times to determine when stock is ready for storage: degree hardening days, oscilloscope-square wave and electrical impedance.

Degree hardening days (DHDs) constitute an indirect measure of seedling condition based on rooting zone temperatures. The assumption underlying the use of DHDs is that root hardiness is prerequisite to successful frozen storage and is promoted proportionately by soil temperatures below 10°C. DHDs are calculated from the cumulative difference between 10°C and daily minimum soil temperature at a depth of 15 cm (cf. Mullin and Hutchinson 1978, Mullin and Parker 1976, Racey 1984). However, it has been found that the underlying assumption of this technique, that exposure of roots to cold temperatures is necessary for successful storage, does not always hold (Racey 1984). Hence, trees may be ready for storage before the number of DHDs indicates that they are ready. For this reason, the physiological condition of seedlings has been measured directly as an indicator of readiness for storage, and the oscilloscope-square wave and impedance techniques have been used for this purpose.

The oscilloscope-square wave technique evaluates the change in wave trace that occurs when a current with a square wave pattern is passed between two pairs of stainless steel pins impaling a seedling stem. The unaltered wave is square in shape but, when passed through the seedling shoot tissues, it is distorted in characteristic patterns. The distortion of the square wave is a function of the impedance across the frequency band of which it is composed. Trees are considered ready for storage after a 21-day period in which at least 80% of sampled trees produce a "left-hand" wave pattern, in which the resistance of the seedling tissues to high frequency currents is high (Day et al. 1985).

The oscilloscope-square wave technique has several shortcomings, including its high cost and technical complexity. What is more serious, though, is the fact that there are documented instances in which square-wave pattern has not been well correlated with level of hardiness or dormancy (Jaramillo 1978, Holbo et al. 1981), and as yet there is nothing in the literature to indicate that the square-wave pattern is well correlated with dormancy, hardiness, or readiness for storage.

The second electrical technique for assessing readiness for storage is measurement of stem electrical impedance. This technique has been developed as a result of many years of research by C. Glerum of the Ontario Tree Improvement and Forest Biomass Institute (1969, 1972, 1977, 1980). Like the oscilloscope-square wave method, it measures the seasonal change in impedance of an electrical current passed through seedling shoot tissue impaled on stainless steel electrodes.

The difference between the impedance and oscilloscope-square wave techniques is that impedance is a quantitative measure of electrical resistance to a set alternating current frequency (1 Khz), whereas the oscilloscope-square wave measures a qualitative change (i.e., the shape of the square wave) across a wide range of frequencies. Electrical impedance values have been shown to be correlated with readiness for frozen overwinter storage of all species so far tested, including black spruce *(Picea mariana* [Mill.] B.S.P.), white spruce, jack pine *(Pinus banksiana* Lamb.), red pine, white pine *(Pinus strobus* L.) and larch *(Larix laricina* [Du Roi] K. Koch) (Racey 1984 and unpublished data).

Electrical impedance is now being used to predict readiness of bare-root stock for overwinter storage at tree nurseries in Kemptville, Orono, Midhurst, Swastika and Thunder Bay, Ontario and at Pineland Tree Nursery in Hadashville, Manitoba. Impedance bridges, staff training and coordination are being provided by the stock production research group at the Ontario Tree Improvement and Forest Biomass Institute (OTIFBI) in Maple, Ontario.

CONTAINER STOCK

Nursery managers can initiate or prevent hardening in container seedlings in greenhouses by modifying photoperiod, fertilization, moisture supply and, within limits, temperature. At present, all container stock is overwintered outside in holding areas. Such holding areas offer a wide range of protection for seedlings. The best holding area designs are those that allow maximum snow accumulation and provide protection from wind. The most effective designs appear to be those with a retractable roof and side walls completely encircling the holding area, with numerous side walls located in series perpendicular to the direction of the prevailing wind. These features allow snow to accumulate within the holding area and minimize snow losses that are due to sunlight or wind. Although an effective holding area structure is needed to reduce losses that are due to winter desiccation, the most crucial aspect of overwintering container stock is the transition from greenhouse to outside environment.

Container seedlings are grown as either single or double crops, in which either one or two crops, respectively, are grown in each greenhouse every year. Double cropping, introduced on a large scale in Ontario in 1982, enables increasing seedling production targets to be met by fewer greenhouses. Double cropping seriously hampers a grower's ability to meet seedling size standards (i.e., minimum height of 10 cm), to harden stock and to move it outside for overwintering within acceptable time frames, since the second crop is not sown until the end of May or the beginning of June.

For spruce seedlings, there is little flexibility in crop scheduling, for a number of reasons. For one thing, crops should be moved outside by the end of October, when the likelihood of relatively mild temperatures (i.e., minimum temperatures above -10°C) is greater. For another, spruce seedlings require from 7 to 9 weeks to initiate buds and develop shoot frost hardiness (Colombo et al. 1984). Therefore, the bud initiation regime should begin no later than the end of August, but to be safe, by mid-August. Finally, second-crop seedlings cannot be sown until the beginning of June, since the first crop must be held inside until late May to avoid spring frosts. Frost hardening of shoots, in response to near-freezing temperatures, occurs much more quickly in pine species than it does in spruce. Therefore, jack pine container seedlings can be moved outside relatively safely by mid- or late August and should become frost hardy within several weeks. Spruce container stock must not be moved outside at the end of August, as it is unable to harden quickly and almost invariably is damaged by fall frosts (Colombo 1982, 1983). Removal of spruce container stock from greenhouses near the end of August fails to take into account the natural time requirement for seedlings to change from active growth to budset and dormancy, with their associated high levels of frost hardiness. Not only are these seedlings vulnerable to fall frosts, but they are unable to develop needle cuticle properly and are consequently at higher risk with respect to desiccation throughout the winter and possibly after outplanting the following year (Colombo and Vanhinsburg, unpublished data). For these reasons most spruce container seedlings in Ontario, as well as in New Brunswick, Nova Scotia and Manitoba, are hardened by means of extended greenhouse culture. In this procedure, seedlings are protected from shoot freezing inside greenhouses until adequate levels of hardiness have developed (Colombo et al. 1984).

With single-crop spruce seedlings, for which the bud initiation regime can be started by the end of July, trees are usually ready to be moved outside by the beginning of October. Extended greenhouse culture and overwintering outside usually pose few problems for these seedlings. However, with second-crop spruce seedlings, particularly those in which the bud initiation regime is delayed until the very end of August or even into September, losses due to root freezing can occur when crops are exposed to lower temperatures (i.e., -15°C or less), either immediately or soon after they are moved outside. Seedlings that do not experience very low temperatures for several weeks after they are placed outside do not usually suffer problems from root freezing.

The use of frozen storage for container stock helps to prevent losses from root freezing and winter desiccation, and permits seedlings to grow beyond the end of August so as to meet height standards, without risk of exposure to very low temperatures outside, since crops can go directly from greenhouse to frozen storage. Extended greenhouse culture and frozen storage appear to be ideal companions. Seedlings can be grown to size and hardened in greenhouses at fairly high temperatures so that they will have greater total dry weight and diameter, lower shoot:root ratios, greater root growth potential and increased bud size (Colombo 1982, Colombo et al. 1986). Because such features favor successful plantation establishment, extended greenhouse culture, used in conjunction with frozen storage, holds the promise of providing an assured supply of seedlings of the highest quality.

Three techniques for assessing readiness for storage have been tested with black spruce container seedlings: oscilloscope-square wave, electrical impedance and frost hardiness testing (Colombo and Cameron 1986). Neither of the electrical techniques proved reliable as detectors of readiness of container stock for storage. Square-wave patterns bore no relation to readiness for storage, as seedlings that survived and those that suffered damage both showed right-hand wave traces, which are supposed to indicate "active" seedlings (Day et al. 1985). Impedance trends were found to be too variable for use in predicting readiness for storage. This variability could have been due to the need to adjust impedance values with seedling diameter as a covariate. Small errors in measuring container seedling diameters could drastically affect adjusted impedance values in comparison with errors attributable to the measurement of relatively large-diameter bare-root stock since impedance varies linearly with the reciprocal of the square of diameter (i.e., an error of 0.1 mm in measuring seedling diameter has a much greater effect if diameter is 1.5 mm than if it is 3.5 mm).

Frost hardiness was found to be well correlated with readiness of black spruce (Colombo and Cameron 1986) and jack pine (Colombo, unpublished data) container seedlings for storage. In this procedure, the frost hardiness of the terminal 2-3 cm of the shoot is determined by the diffusate-electrical conductivity method (Colombo et al. 1984). Excised shoot tips are immersed in water after freezing. Damage caused by freezing is indicated by an increase in electrical conductivity of the water, caused by leakage of cell solutes through damaged cell membranes. Staff at OTIFBI arranged for trained personnel to conduct frost hardiness tests and provided the necesssary equipment. Facilities for such tests are now located at OTIFBI and in the Northern and Northwestern Regions of the Ontario Ministry of Natural Resources, and there are plans to establish a similar laboratory in the North Central Region in 1988. Hence, equipment and personnel to assess readiness of container stock for storage are already in place.

Trials have been conducted that verify the suitability of frost hardiness testing for determining readiness of container stock for storage, and indicate that the field performance of black spruce and jack pine container stock stored over winter is equal to that of stock stored outdoors (Colombo, unpublished data). A semi-operational trial, currently being conducted by the Northern Region, should indicate the logistical requirements for large-scale storage of container stock. As a result of these developments, it is conceivable that operational storage of container stock may be in place in Ontario before the end of this decade.

OTHER FACTORS AFFECTING THE SUCCESS OF OVERWINTER FROZEN STORAGE

Determining readiness for storage is only one of a series of steps necessary for successful plantation establishment with overwinter frozen stored stock. Critical factors affecting the success of frozen storage include readiness for storage, conditioning regimes, handling procedures, packaging methods, storage temperature, duration of storage, post-storage conditioning, holding practices, field transportation, preplanting treatments, planting procedure, and post-planting stresses. Failure to follow any one of these steps properly can adversely affect plantation establishment. Consequently, poor field performance of frozen stock stored over winter should not necessarily be attributed to the use of frozen storage. Although this may appear obvious, it is important to state it here, since problems that occur after a new practice is implemented are often blamed solely on the practice itself, with or without justification.

In summary, both bare-root and container stock of a wide range of species can be frozen and stored successfully over winter. It is possible to determine readiness of bare-root stock for storage by using electrical impedance and readiness of container stock by using frost hardiness testing techniques. Frozen storage offers both logistical and biological advantages over overwintering stock outside.

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PLANTING STOCK QUALITY IS FITNESS FOR PURPOSE

R.F. Sutton
Research Scientist
Canadian Forestry Service
Great Lakes Forestry Centre
Sault Ste. Marie, Ontario

Abstract.—The term quality *derives from the Latin* qualis, *meaning "of what kind". In relation to planting stock, quality is the degree to which any designated stock proves to be suited to the purpose for which it was produced. Clear expression of objectives is therefore prerequisite to any determination of planting stock quality. Planting stock quality therefore depends not only on the characteristics of the stock but also on what is expected of the stock in the situation in which it is used. Stock characteristics alone determine performance potential, not quality.*

Résumé.—Le mot qualité vient du latin qualis *qui signifie de quelle sorte, de quelle nature, de quelle espèce. La qualité du matériel de reproduction est son degré d'adéquation avec l'objectif pour lequel il a été produit. Il est donc essentiel de définir clairement les objectifs à atteindre avant de déterminer la qualité du matériel de reproduction. La qualité du matériel de reproduction dépend non seulement des caractères du matériel mais également de sa performance dans les conditions stationnelles prévues. Les caractères du matériel déterminent uniquement son potentiel de rendement, non pas sa qualité.*

INTRODUCTION

Those of you who were fortunate enough to take part last December in Timmins in the excellent seminar on "Stock Standards and Early Plantation Performance" organized by the Northern Forestry Development Group of the Ontario Ministry of Natural Resources may remember that, at the beginning of the opening session, I asked everyone present to write down on a card the meaning of the term "quality". I suggested that you not bother to try to define "stock quality" or "planting stock quality" but simply write down your definition of the term "quality" (Sutton 1987a). One hundred and four cards were collected.

The results of the survey, which have been included in the published proceedings (Anon. 1987), are instructive. About one-sixth of the definitions expressed explicitly the idea that quality is fitness for purpose. Another sixth of the definitions incorporated some, often vague, sense of purpose. A further third of the definitions equated quality with excellence or superiority independently of purpose. Other definitions leaned heavily on a wide range of unspecified standards.

The survey clearly shows what widely different meanings may be attached to the term "quality" even among those who are directly and intensely concerned with planting stock production and plantation establishment.

The question is much more than one of academic interest. To my mind, a clear appreciation of what is meant by "quality" and "performance potential" is prerequisite to efficient and effective plantation establishment.

QUALITY: ANALOGY BETWEEN PLANTING STOCK AND KNIVES

Let us first consider how we use the term "quality" not, for the moment, in the context of planting stock, but in relation to, say, knives.

A knife, as the Oxford dictionary (Onions 1955) will tell you, is "a cutting-instrument, consisting of a blade with a sharpened longitudinal edge fixed in a handle, either rigidly as in *table-knife* or *sheath-knife*, or with a joint as in *pocket-knife*". The idea of purpose is already clearly evident in the definition. Most of us have a pretty good idea of what kind of knife we need for a given purpose, and we generally have little difficulty in assessing how well or how poorly a knife serves the purpose for which we have chosen it. In other words, we are able to assess the quality of the knife. What we demand of a knife depends on the purpose to which we put it; sharpness and temper of the blade may be the prime considerations, but size and morphology, balance, and appearance may be of equal or, for some purposes, even greater importance. The requirements vary with the purpose. The quality of a given knife is determined by the degree to which the specified requirements are exhibited by that knife.

PLANTING STOCK QUALITY (PSQ)

Though initially less obvious, the situation with respect to planting stock is very similar. Planting stock is produced as a means of achieving the objectives of management (OOM) and giving effect to the forest policy of the organization. The production of planting stock is not itself the goal. That it has often been so regarded has caused much of the confusion that still surrounds the question of planting stock quality.

If, for example, a stock production system is geared to the goal of annually shipping x million acceptable (i.e., with no apparent cause for rejection) units of planting stock to the field, the purpose for growing the stock is reduced to that of meeting a quota. If x million plants are shipped and accepted by the user, the purpose is fulfilled and the quality is 100%, notwithstanding the condition of those trees and their subsequent performance in the field, and notwithstanding the objectives of management that set in motion the chain of events leading to the production of the stock.

It is to the achievement of those objectives of management that the production of stock must be geared, and this is the only appropriate basis for determining the quality of the planting stock. "The quality of planting stock is the degree to which that stock realizes the [overall, not just the nursery] objectives of management" (Willen and Sutton 1980). "Clear expression of objectives is therefore prerequisite to any determination of planting stock quality. Planting stock may be perfectly fit [i.e., 100% quality] for one purpose and perfectly unfit [i.e., 0% quality] for another" (Sutton 1982).

To determine the quality of planting stock, therefore, "not only does performance have to be determined, but performance has to be rated against the objectives of management" (Sutton 1987a).

PLANTING STOCK PERFORMANCE POTENTIAL (PSPP)

Further confusion arises if the term "planting stock quality" is used when what is really meant is "planting stock performance potential" (PSPP). Whereas, because of site conditions, the *actual* performance of any given batch of outplanted planting stock is determined only in part by the kind and condition of the stock itself, PSPP is an intrinsic property of the planting stock, just as is Root Growth Capacity (RGC).

The potential for survival and growth of a batch of planting stock may be estimated from some feature or character of the planting stock or sample thereof. PSPP is impossible to estimate reliably by eye because outward appearance, especially of stock that emerges from refrigerated storage, can be totally deceiving — even to experienced foresters who would be offended if they thought their ability to recognize good planting stock was being questioned. However, that greatest of teachers, Bitter Experience, has often enough demonstrated the fallibility of such assessment. The physiological qualities of planting stock are hidden from the eye and must be revealed by testing before PSPP can be reliably estimated.

One of the hidden physiological qualities of planting stock, for example, is the readiness of that stock to produce new root growth. This readiness cannot be determined by eye. Two batches of planting stock, even of the same provenance and seed lot, can be identical in morphological appearance and yet so different in PSPP that one batch will thrive after planting while the other, in the same planting environment, will fail. This accounts for the increasing use of physiological testing, e.g., determinations of RGC, in which the behavior of a sample of the stock in test conditions is used as an aid in estimating PSPP. Certainly this entails exposing the sampled stock to an environment that influences, and even determines, the results obtained, but the environment is standardized, reproducible, and constitutes part of the assay procedure. The test environments employed are often salubrious and unstressful; in RGC testing, for instance, attempts are made to provide stock with conditions that are optimal for root growth during the test period. There is no reason to suppose, however, that stressful tests would be any less suitable, and indeed they may be more so (cf. Hermann and Lavender 1979). In assessing PSPP, actual performance in test conditions is irrelevant. What counts is the relationship between the test values and the ability to achieve the OOM. That such relationships are not easily determined may be illustrated by the literature on RGC (cf. Sutton 1987b).

RGC AND PSPP

RGC is a quantification of the root growth produced by trees in a given time in a benign environment (Sutton and Tinus 1983), but rigorous quantification is extremely difficult. In any event, the results obtained are highly dependent on the test environment, small differences in which produce large RGC differences (Sutton 1975). The difficulty of quantification has led to various shortcuts and approximations, and these add to the already considerable problem of relating RGC to field performance. The first- through fifth-year performance of jack pine *(Pinus banksiana* Lamb.) and black spruce *(Picea mariana* [Mill.] B.S.P.) in outplantings in boreal Ontario, for instance, was virtually unrelated to RGC expressed as the number of new roots less than 1 cm, the number of new roots 1 cm long or longer, or the mean aggregate length of roots 1 cm long or longer; only RGC expressed as the mean of the mean length of new roots 1 cm long or longer per seedling gave a significant ($P = 0.01$) relationship in both species, and this was for survival only (Sutton 1987b).

The importance of root growth in the establishment of outplants can be presumed (Burdett et al. 1983). In addition the thesis that the greater the RGC of outplanted stock, the greater will be the ability of that stock to perform well, would seem to be reasonable (Sutton 1980). Yet the relationship is not well supported by published evidence (Sutton 1987b). Many of the data in the literature, reviewed by Ritchie and Dunlap (1980), relate to survival differentials among different stock lots differing greatly in RGC.

FIELD PERFORMANCE, PSPP, PSQ, AND OOM

In the hope of clearing up any remaining uncertainties about the interrelationship among field performance, PSPP, and PSQ, I will give you a few examples.

The field performance of an outplant is determined by its PSPP *at the time of planting* and the constraints to which the outplant then becomes subjected. Two outplants may perform similarly, even though they differ greatly in PSPP, if the higher PSPP is neutralized by greater constraint (Fig. 1). Conversely, two outplants with identical PSPPs will perform quite differently if they are subjected to differential constraint.

With respect to the OOM, it is the level at which the objectives are set that will determine PSQ. PSQ can be changed merely by changing the objectives (Fig. 2). If the objective had been to obtain 120 units of performance, whatever they may be, and 120 units were actually obtained, this would mean a PSQ of 100%. If the objective had been to obtain 160 units of performance, however, an actual performance of 120 units would mean a PSQ of 75%. The stock is the same, the performance is the same, but the PSQ is different because the objectives are different.

OBJECTIVES OF MANAGEMENT

I hope that by now you will not be surprised to learn that I regard the lack of clearly defined OOM as the central problem in regeneration silviculture.

Definition of objectives that are attainable at affordable cost -- in other words, objectives that are realistic — is an exceedingly difficult task that requires highly skilled evaluation of many interrelated items. Many of the ecological, edaphic, physiological, climatological, economic, and even sociological data needed in the formulation of sound OOM are either insufficient or not available.

The train of events that must precede the timely arrival of planting stock at a planting site suitably prepared to receive that stock is complex and costly. This train of events is initiated to realize some objective(s) that will help to effect the policy of the initiating organization. Unless the objectives are realistic, and unless they are specific and defined, there is no logical basis and little incentive either for evaluating the results of the forestation effort or for seeking to improve it.

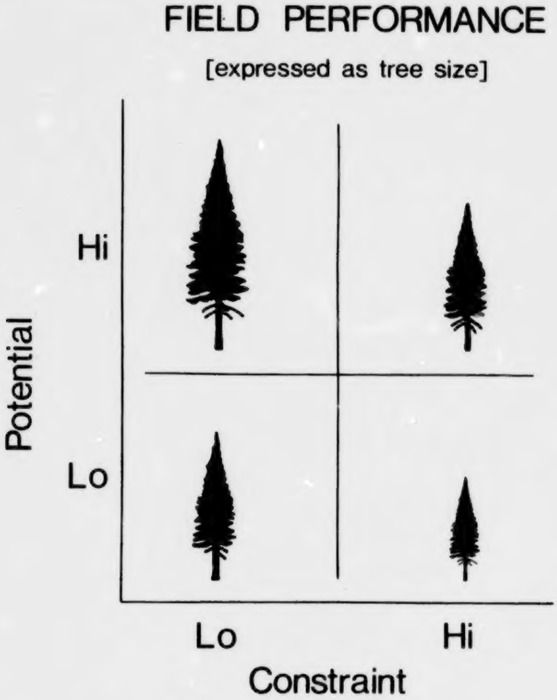
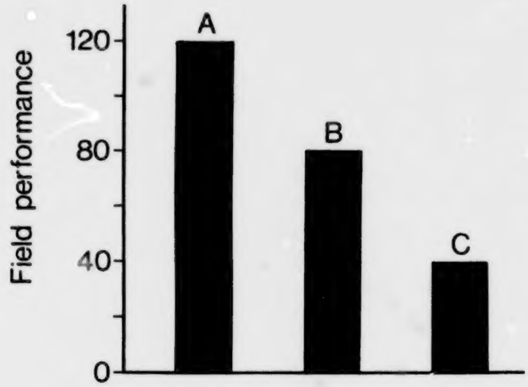


Figure 1. Idealized representation of the influence of planting stock performance potential and post-planting constraint (stress) on field performance of outplants.

SUMMARY

The field performance of outplants is determined by the interaction between planting stock performance potential at the time of planting and the environment experienced by the outplant. Planting stock quality is the degree to which that stock achieves the purpose, enunciated in the objectives of management, for which it was produced and planted. The determination of planting stock quality therefore requires not just the determination of performance but the determination of performance *in relation to* the objectives of management.



Objective	QUALITY %		
160	75	50	25
120	100	67	33
80	150	100	50
40	300	200	100

Figure 2. Idealized representation of the relationship between field performance, management objective, and planting stock quality. Note particularly that planting stock quality can be changed merely by changing the objectives; e.g., a field performance level of, say, 80 units would equate with 50, 67, 100, or 200% planting stock quality

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EVALUATION OF PLANTING STOCK QUALITY

C. Glerum
Principal Scientist
Ontario Tree Improvement and Forest Biomass Institute
Ontario Ministry of Natural Resources
Maple, Ontario

Abstract.--The quality of planting stock is assessed by means of 1) morphological parameters such as height, diameter, oven-dry weight, root area or volume, needle length, and bud size, and 2) physiological parameters such as root growth capacity, nutrient content, water relations, dormancy, frost hardiness, electrical impedance, food reserves and photosynthesis. The applicability of all these parameters is discussed within the framework of the planting stock quality concept that has, as its objective, the optimization of field performance (i.e., survival and growth).

Résumé.--On évalue la qualité du matériel de reproducton en fonction de 1) paramètres morphologiques comme la taille, le diamètre, le poids anhydre, la surface ou le volume racinaire, la longueur des aiguilles et la grosseur des bourgeons, et de 2) paramètres physiologiques comme le potentiel de croissance des racines, la teneur en substances nutritives, l'état hydrique, la dormance, la résistance au froid, l'impédance électrique, les réserves alimentaires et la photosynthèse. L'auteur examine l'applicabilité de ces paramètres à l'évaluation de la qualité du matériel de reproduction, qui vise à optimaliser le rendement des plantations (c'est-à-dire, le taux de survie et la croissance des arbres).

INTRODUCTION

The concept of planting stock quality is not as readily understood as one might expect. As defined by Sutton in the previous paper and elsewhere (1980), the quality of planting stock is the degree to which that stock realizes the objectives of management at minimum cost. Quality is fitness for purpose. To that end we want our trees to grow as fast as possible after outplanting so that we can obtain the earliest possible plantation establishment and, consequently, the shortest possible rotation (Fig. 1).

Planting stock quality cannot be determined by one type of measurement. The stock must be monitored throughout the entire nursery production cycle, from seedling to outplanting.

Nurserymen monitor various parameters of the stock throughout the nursery phase until shipping, at which time the stock becomes the

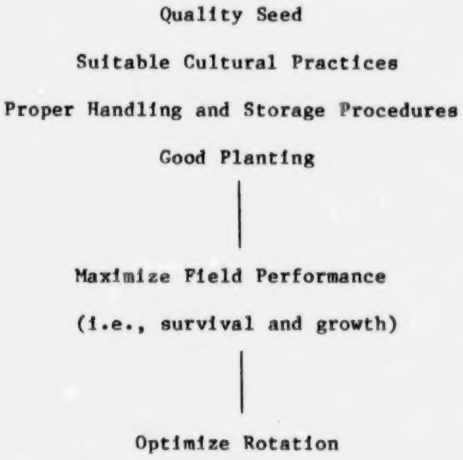
Quality Seed
Suitable Cultural Practices
Proper Handling and Storage Procedures
Good Planting
Maximize Field Performance
(i.e., survival and growth)
Optimize Rotation

Figure 1. Flow chart outlining the concept of planting stock quality.

responsibility of the forest manager, whose main interest is the quality of the stock. The fewer parameters the manager has to deal with in relation to quality, the better. The manager's main requirement is for high-quality stock with high survival and fast growth, which translates into early plantation establishment and the shortest possible rotation. After all, the ultimate test of a tree seedling's quality is its survival and growth after outplanting.

No single parameter can measure seedling quality, but a number of parameters are used to assess seedling quality. These planting stock quality parameters fall into two broad groups, morphological (Fig. 2) and physiological (Fig. 3), which will be discussed briefly in this paper.

MORPHOLOGICAL PARAMETERS

The parameters most frequently measured at the nursery at time of lifting and packaging are height, diameter, oven-dry weight, top:root ratio and root-area index or root volume. Of these parameters, diameter, root-area index, root volume and oven-dry weight are the most useful in assessing planting stock quality. Nevertheless, the correlation of these parameters with subsequent field performance will explain, at best, 40% of the variation. Top:root ratio (T:R), though one of the more commonly measured parameters, is one of the poorest in its predictive ability (Racey et al. 1983). It should be realized that T:R does not really reflect a well balanced, compact seedling, because of the manner in which it is calculated. Furthermore, it should not be confused with the sturdiness of the seedling, which is generally expressed as a height:diameter ratio.

In Ontario root-area index is measured, while in other provinces root volume is more frequently used. The correlation between root area, root volume and root oven-dry weight is high; therefore, any one of these parameters can be substituted for another (Racey 1985).

The number of parameters measured depends in part on economics and in part on the stock type. The parameters mentioned above are measured for all bare-root stock types. The most frequently measured parameters for container stock types are height, root-collar diameter (RCD) and oven-dry weight.

Nursery needle length is a good predictive parameter of stock quality but its usefulness has only recently been demonstrated by Paterson and Fayle (1984) and Paterson (1987). The work on needle length has been done with red pine (*Pinus resinosa* Ait.) but there is sufficient evidence to suggest that it would be applicable to most if not all coniferous species. Trees with short needles in the nursery have lower survival and total height after outplanting than those with long needles, as is still evident 8 years after

Height

Diameter (i.e., root-collar diameter)

Height:diameter ratio

Oven-dry weight

Top:root ratio

Root area index

Root volume

Needle length

Bud size
    bud length
    number of needle primordia

Figure 2. Morphological parameters used to measure planting stock quality.

Root-growth capacity

Nutrient content

Water relations

    plant moisture stress

Dormancy

    electrical impedance

Frost hardiness

Photosynthesis

    chlorophyll content

Biochemical measurements

    carbohydrates (sugars, starch, etc.)

    lipids, proteins

Figure 3. Physiological parameters that are used or have the potential to measure planting stock quality.

outplanting (Fig. 4). Even when there were no significant differences in original nursery heights between seedling groups selected by needle length, trees with nursery needles longer than 90 mm were significantly taller after 8 years than those with needles shorter than 70 mm. These data show that needle length is a more sensitive predictor of field performance than height. The data base for red pine needle length is large enough that one can use this parameter operationally, but it still needs to be developed for all other species.

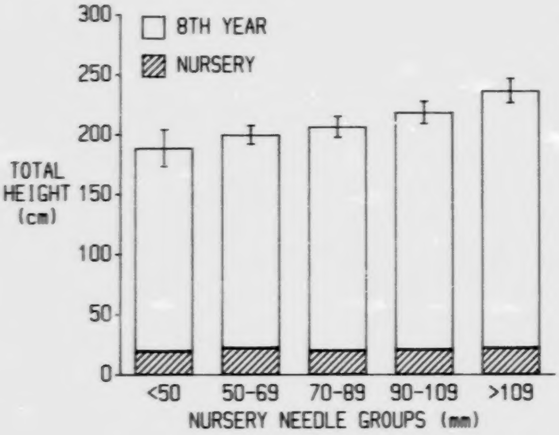

Figure 4. Average height of 3+0 red pine at time of planting (nursery height) and 8-year total height by nursery needle groups. Confidence limits are at the 95% level (from Paterson 1987).

Bud size, which is a good indicator of subsequent field performance, can be determined by measuring bud length and/or bud diameter, or by counting the number of needle primordia in the bud. At present, the use of bud length and/or diameter is sporadic (Thompson 1985). Needle primordia assessments are done extensively on black spruce (*Picea mariana* [Mill.] B.S.P.) containerized seedlings. These assessments are done in concert with freezing tests (Colombo et al. 1984). Together they assist us in determining when the stock is ready to be moved from the greenhouse to the outside for overwintering. The number of primordia is a good indicator of potential growth. Furthermore, a well developed bud indicates that nursery practices have permitted completion of all growth processes.

In spruce, needle primordia occur in symmetrical rows, which makes primordia assessment operationally feasible. In pines, however, the needle primordia occur in nonsymmetrical rows, which makes their assessment time-consuming and their operational use probably impracticable. Bud length and diameter are possibly better parameters than primordia assessment for the pines.

Although morphological parameters are useful indicators of quality there is still a great need for physiological parameters, because it is the physiological state of the seedling at the time of planting that will determine seedling survival and subsequent growth.

PHYSIOLOGICAL PARAMETERS

Root-growth capacity (RGC) is at present one of the most important and most widely monitored physiological parameters for assessing tree seedling quality. Root-growth capacity is the ability of a seedling's root system to initiate and/or elongate roots when planted in an environment that is conducive to root growth. Such an environment can be a peat or sand medium placed in a growth chamber or greenhouse for a number of days. Standard tests range from 7 to 28 days in length. A seedling that produces many new roots has a high RGC and one that produces few or no roots has a low RGC. In the literature RGC is also referred to as root-growth potential (RGP), root-regeneration potential (RRP) and root-regeneration capacity (RRC).

A seedling with high RGC is more likely to become rapidly established after outplanting because it has a greater chance of exploiting the moisture and nutrients in its immediate vicinity. RGC tests are being conducted by many nurseries on the west coast. Ontario nurseries should be encouraged to do likewise. Operationally, there is a need to standardize RGC tests with respect to duration (7 to 28 days), type of growing medium (i.e., peat, sand, hydroponic [Ritchie 1985] or aeroponic [Day et al. 1985]), medium temperature, air temperature and light (i.e., intensity and photoperiod). A good account of RGC is given by Ritchie (1985) and the latest review on this subject is provided by Burdett (1987).

The importance of nutrient content in assessing seedling quality has yet to be determined. A consistent relationship between any aspect of seedling nutrient content and seedling quality has not been found, except in cases of severe deficiency (Ritchie 1984). The role of nutrient content and seedling quality is a complex one and should not be dismissed lightly. Years of intensive investigations are needed. We have a large data base for nutrient concentrations of our coniferous bare-root stock but not for our container stock types. The acceptable nutrient concentration ranges for macronutrients and micronutrients are readily available for most tree species and for our Ontario species they are provided by Armson and Sadreika (1979). A useful account of nutrient status is given by Landis (1985). As long as none of the nutrients is limiting (i.e., as long as each is within acceptable ranges) seedling quality can be considered high.

All aspects of seedling physiology are influenced by the seedling's water status. The literature on this topic is voluminous and complex. It is obvious that seedling water status influences seedling quality. Seedlings should be planted only when they are under minimum moisture stress. There are many methods for determining the moisture status of a seedling (Joly 1985, Ritchie 1984). One of the most popular is the pressure chamber, which is used to determine plant moisture stress (PMS). Pressure chambers are used to determine PMS at several nurseries in North America and all Ontario nurseries should be encouraged to determine PMS at time of lifting, shipping and planting.

There is a considerable body of literature that illustrates the use of the pressure chamber. What still needs to be determined for most species is the critical PMS, at which permanent, irreversible damage occurs to the seedling. This value, which is also called the wilting point, has been found to depend on the phenological state of the seedling (Fig. 5). The critical PMS follows a seasonal pattern. It is high (28 bars) when the stock is dormant and considerably lower (14 bars) when the stock is actively growing. Once these critical PMS values have been established, PMS determinations will be a valuable parameter in determining seedling quality.

Dormancy can be defined as a condition in which a tissue predisposed to elongating does not do so even if environmental conditions are suitable for growth. This simple definition is in stark contrast to the physiological complexities of dormancy. However, from a nurserymen's point of view, dormancy sets in when bud initiation occurs and the seedling is dormant when all buds have been formed. The seedling comes out of dormany when bud swell and bud break occur. No practical methods are at present available to determine the stage of dormancy in nursery stock. Bud set and bud break still provide the most practical indication of when the seedlings go into and out of dormancy, respectively.

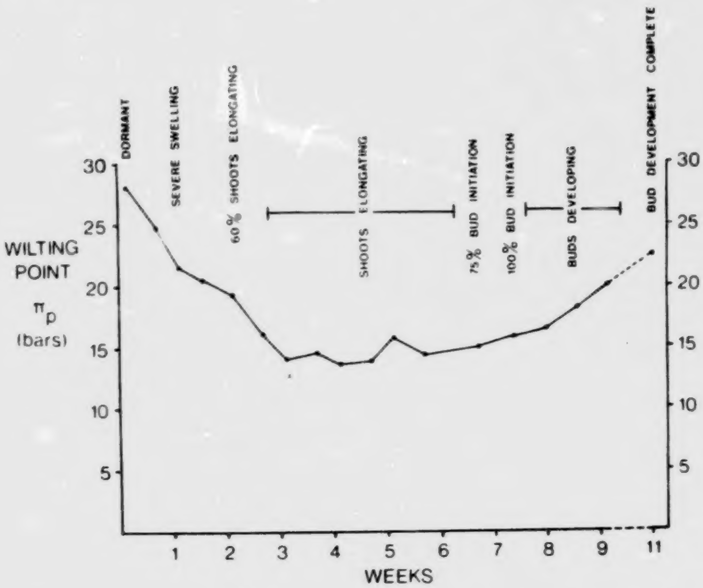

Figure 5. Relation between stage of shoot growth (phenological development) and wilting point of black spruce container seedlings. Wilting point is the critical plant moisture stress point (from Colombo 1985).

Although the dormancy status of a seedling does not describe the quality of that seedling, it is a useful means of approximating its physiological state. Generally, dormant seedlings are more resistant to stresses than actively growing seedlings (e.g., see Fig. 5). Therefore, seedlings should be handled (i.e., lifted, stored and outplanted) when dormant. It is for this reason that a considerable research effort needs to be directed towards understanding seedling dormancy in the context of the nursery production cycle and subsequent outplanting.

Electrical impedance, which at one time was thought to measure frost hardiness and/or dormancy, appears to be more an indicator of metabolic activity than of frost hardiness or dormancy as such (Glerum 1980). Electrical impedance has been developed to the point that it is now being used in Ontario to determine when bare-root nursery stock is ready for lifting in the fall for overwinter frozen storage.

Frost hardiness testing is now an accepted practice to determine when dormant seedlings are ready to go into overwinter frozen storage and likewise when container seedlings, especially black spruce, are ready to be moved out of the greenhouse into outside holding areas or into overwinter frozen storage (Colombo et al. 1984). The latter is not yet operational in Ontario, but is under investigation. There is little doubt that seedlings have to be sufficiently hardy before they can be set outside, where temperatures of -30°C are common, for overwintering, or placed in overwinter frozen storage.

Frost-hardiness testing involves subjecting seedlings or their parts, such as twigs, to a range of freezing temperatures in a freezing chamber. This temperature range will be in descending order as the fall progresses. Freezing rates should be gradual, i.e., 2-5 Celsius degrees per hour. Thawing rates should also be gradual. Injury is assessed after freezing. At present there are only two operational techniques for assessing injury caused by freezing: the growth or browning test for the whole seedling, and the electrolytic conductivity method with the index of injury. Determining the frost hardiness of a seedling requires a thorough knowledge of the frost hardiness process as outlined elsewhere (Glerum 1985).

Photosynthetic rates in trees are sensitive to many internal and external factors and could theoretically be used to assess tree seedling quality. Photosynthesis is easily measured in the laboratory with an infrared gas analyzer, but not in the field. Equipment such as the portable infrared gas analyzer is being developed to monitor photosynthesis in the field, and the results are encouraging. However, considerable research is needed before photosynthesis becomes a feasible parameter of stock quality.

Chlorophyll content has been advocated as an indicator of seedling quality. Simple methods for chlorophyll determination that can be used in almost any nursery are now available (Linder 1980). However, while strong correlations have been shown to exist between chlorophyll concentration and nitrogen content, the relation between the former and general stock quality has not yet been addressed adequately in spite of its obviously vital role in photosynthesis.

There is no simple biochemical compound that indicates seedling quality. Most of the biochemical work on seedling quality deals with food reserves, which occur predominantly in the form of carbohydrates, such as starch and sugars. However, other groups of compounds such as lipids and proteins should not be overlooked. Food reserve accumulation begins in late summer when the growth processes begin to slow down. The longer the period between growth cessation and lifting or freeze-up, the more time the seedling has to accumulate food reserves. These food reserves are used during storage, especially if storage temperatures are above 0°C, and during periods when no photosynthesis can take place (i.e., during handling and planting). There is little doubt that food reserves are critical to seedling quality (Ritchie 1984), but since carbohydrate chemistry is complex and interconversions among carbohydrates occur continuously, little progress has been made in this area.

In concluding this section on physiological parameters, it should be realized that some of these parameters such as dormancy and frost hardiness are measures of a physiological state and not a measure of seedling quality. However, some generalizations have to be made with respect to physiological state and certain stresses such as frost, heat and drought. It is for this reason that dormancy and frost hardiness are included in the list of physiological parameters.

CONCLUSIONS

After a brief examination of all available parameters that show promise as means of determining planting stock quality, the nurserymen and the forest manager still have to decide which ones should be measured. Although height in general is a poor parameter, it is one of the easiest to measure and it is necessary to ensure adequate size for outplanting. Therefore, it should be included in the list of morphological parameters to be measured. Other important parameters are diameter, root area index or root volume. For spruce container stock the number of needle primordia in the bud should be included as well as oven-dry weight.

Of the physiological parameters, root-growth capacity and plant moisture stress should be measured. If fall lifting of bare-root stock for overwinter frozen storage is desired, electrical impedance should be measured. Frost hardiness should be tested when spruce container stock is to be overwintered. Many of the other parameters require considerable research and subsequent development before they will become operationally feasible.

It should be realized that these parameters evaluate the performance potential of the stock and that even if all the parameters measured indicate that the stock is of high quality, proper handling and planting are still necessary if one is to achieve optimum field performance.

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PHYSIOLOGICAL RAMIFICATIONS OF STRESS DURING HANDLING, STORAGE AND TRANSPORTATION OF SEEDLINGS

D.R. DeYoe
Seedling Physiologist
MacMillan Bloedel Limited
Land Use Planning Advisory Team
Woodlands Services Division
Nanaimo, British Columbia

Abstract.—How a seedling is perceived—as a complex infant organism or as an inanimate object of economic value—will influence how it is treated. An awareness of the potential impact of stress on seedling survival and growth can be useful when one is trying to justify costs associated with operational improvements. Seedling stress is a function of imbalances and/or extremes in temperature, light, moisture, atmosphere, nutrition and physical/mechanical factors. Stress events are cumulative, each event stimulating the seedling to respond in a fashion that tends to shift metabolism toward adjustment and repair instead of development and growth. Seedling stress response and recovery time depend on the duration, intensity, timing and frequency of stress events. If our perception of stress is not in tune with that of the seedling, the "events" associated with handling, storage and transportation will limit our expectations of seedling performance.

Résumé.—Notre façon de percevoir un semis--comme un très jeune organisme complexe ou comme un objet inanimé n'ayant qu'une valeur purement économique--influencera le traitement que nous lui accorderons. Il peut être utile de connaître l'impact éventuel de facteurs agressants sur la survie et la croissance de semis lorsqu'on tente de justifier les coûts rattachés à des opérations d'amélioration. L'agression subie par un semis est fonction de déséquilibres et (ou) de variations extrêmes de la température, de la lumière, du degré d'humidité, de l'atmosphère, des teneurs en éléments nutritifs et de facteurs physiques/mécaniques. Les épisodes agressants ont des effets cumulatifs car chacun d'eux force le semis à réagir d'une façon particulière, le métabolisme de la plante tentant généralement de s'adapter et de se rétablir plutôt que de favoriser le développement et la croissance. La réaction du semis et la longueur de la phase de récupération dépend de la durée, de l'intensité et de la fréquence de l'épisode agressant ainsi que de la période pendant laquelle il se produit. Si la façon dont nous percevons une agression ne concorde pas avec celle du semis, les "incidents" survenant lors de leur manutention, de leur conservation, de leur entreposage et de leur transport limiteront la performance à laquelle nous nous attendons.

INTRODUCTION

There are numerous opportunities for stress to seeds or seedlings between the time cones are collected and seedlings are planted. When the seed or seedling is stressed, it shifts its priorities from the metabolic processes[1] of development and growth to those responsible for adjustment and repair (Bazzaz et al. 1987, Bloom et al. 1985).

Recovery to the prestressed condition requires time, energy, substrates[2] for repair, and the absence of further stress events (Chapin et al. 1987, Hoque 1982). Unfortunately, the potential for stress events is high during the reforestation process (DeYoe 1986). Those responsible for handling stock must take every precaution to insure that the frequency, duration, and intensity of stress events are minimized, and that any exposure to stress occurs when seedling resistance is high (DeYoe 1986, Duryea 1985b, Kauppi 1984).

Stress events registered by the seedling reflect imbalances and/or extremes in temperature, water, nutrients, light, soil and atmospheric chemistry, and physical conditions (Levitt 1980a, b). The initial impact on the seedling occurs at the cellular level, where the signal is received, translated into plant language, and expressed as a "stress" response.

Maintaining stock health during handling will improve survival and growth. However, links in the "handling chain" weakened by poor planning will increase the likelihood that stresses inherent in the planting site will be detrimental. Site-related stresses are expensive to minimize, difficult to predict, and become increasingly hazardous to the seedling as site quality deteriorates. Precautions for maintaining seedling health must begin during culture and continue through planting; otherwise, the risk of failure will be high, even on mild sites (DeYoe 1986; Tabbush 1986, 1987).

SEEDLING STRESS—EASY TO MISS

If we cannot tell by looking at a person whether he is healthy or fighting the flu bug, should we expect to make that distinction in seedlings? Seedlings may look fit, but they may be experiencing serious physiological trauma. This is frequently the case when poor quality control has permitted handling practices to deteriorate. Most stresses arising from poor handling practices are subtle (Table 1), so that the seedling appears perfectly healthy until after planting, when site stresses assist in expressing true seedling status.

Table 1. Types of seedling stress and situations in which stress can occur.

Stress	Operational Situations
Frost	* late fall freeze that kills stem or roots * freeze-storage without proper freezing or thawing technique * freezing during site storage on upper-elevation sites
Desiccation	* root drying during lifting, temporary storage, and processing * drying due to vapor loss through holes in bags * condensation on inner surfaces of boxes in response to evaporative losses from heating during handling
Flooding	* transient waterlogging in container cavities during culture * exposure of roots to excess moisture in planting bags * prolonged root dipping
Physical abuse	* disease during culture * simple handling of seedlings when stress resistance is low * root damage during lifting or processing * jarring or shaking of bags/boxes during transit * slapping roots against an object to remove soil or ice prior to planting
Heating	* faulty cold storage facilities * transportation without refrigeration * local storage without refrigeration * transport to the site without proper insulation from radiation or heat sources

NOTE: Stress can be subtle. Individual or cumulative events can gradually reduce seedling vigor, yet never be noticed until after the occurrence of mild site stresses in spring.

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[1] The multitude of chemical reactions occurring in plant cells that are the essence of daily function.

[2] Representative of a wide array of chemical compounds in plant cells that are used in creating products designed for a specific purpose.

Seedling vigor tests provide a mechanism for assessing "invisible" damage and should be considered whenever poor seedling health is suspected (Duryea 1985a). Traditionally, tests for monitoring seedlings were conducted at the nursery before their transfer to the field. Consequently, abuses during transit, local storage, transport to the site, and planting were rarely registered.

Current research in Canada is providing physiological techniques for quick, reliable seedling evaluations (Colombo 1987, DeYoe and Drakeford 1987, Kim et al. 1987, Vidaver and Binder 1987). Beware! Trying to use one tool for all purposes is unrealistic. Would you feel secure having a doctor rely on a single test to assess your physiological status and "predict" your future performance?

Seedlings encounter an overwhelming number of stress events between cone collection and establishment. Seedlings are "infant" organisms; they are more sensitive to stress than "teenagers and adults", and less capable of recovering from multiple stress events. Hence, care must be taken at this early stage to ensure cost-effective reforestation.

IS STRESS CUMULATIVE?

Have you ever had a cold and been forced to work in cool, damp weather? This type of stress to your system frequently leads to upper respiratory infection. If you continue to push yourself instead of resting, pneumonia is the likely outcome. When this occurs it does not take much additional stress to cause death, particularly in a young infant.

When one stress after another is encountered from the time the seed (an encased embryo) is collected to the time the seedling (a developing infant) is established, the consequences of cumulative stress can be devastating. The lack of appreciable recovery time between stress events interrupts the "healing" process and aggravates the situation. (Would you rather twist your knee at the beginning, or the end, of the rugby season?)

The problem confronting us now is perception. We simply need a better understanding of stress in tree seedlings. We need to know what constitutes a stress event, what is required for recovery, and how to resynchronize seedling development. Being aware of stress and how it affects plants is the first step. To accomplish this, we need to probe the seedling to see what makes it tick (Kozlowski 1979; Levitt 1980a, b).

TO THE SOURCE—THE CELL

Figure 1 shows a plant cell in cross section (Kramer and Kozlowski 1979, Lehninger 1982). The *cell wall* provides each cell with the skeletal structure that allows the seedling to support itself vertically. Inside the wall is the *cell membrane,* which confines the cell solution. The cell solution, or *cytoplasm,* contains a variety of ions and solutes[3], important cell regulators (DNA, enzymes, pigments, etc.) and membrane-bound organelles. The organelles include:

- the *nucleus,* the source of genetic information
- the *chloroplast,* where light energy is converted to chemical energy that the plant can use to produce food from carbon dioxide and water

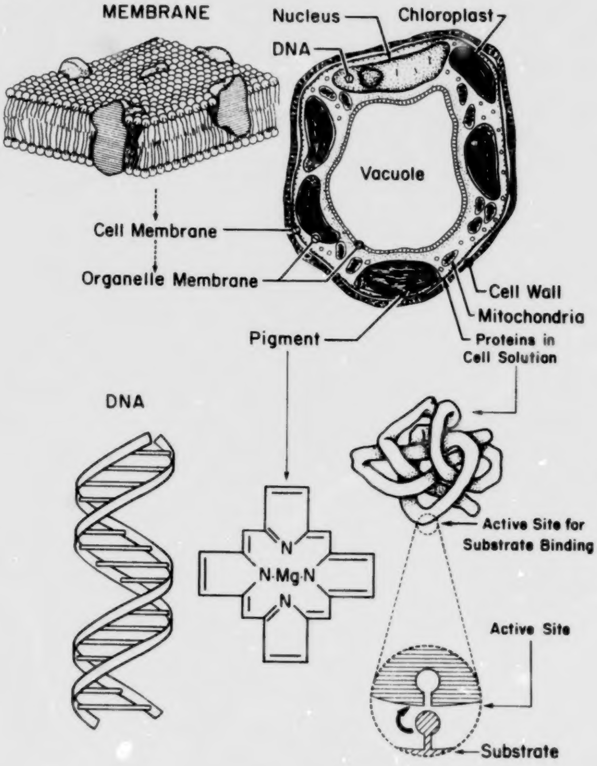

Figure 1. A mesophyll, or photosynthetic, cell found in conifer needles.

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[3] Sugars, amino acids, proteins, and other carbon-based compounds dissolved in the cell solution.

- the *mitochondrion*, where food is processed to generate energy and heat

- the *vacuole*, where a wealth of components, serving a variety of functions and potentially toxic to cytoplasmic regulation, is housed.

Embedded in cell and organelle membranes are "transporters", proteins that control cellular traffic.

Think of the cell wall as a hollow sphere of steel wool. Inside this sphere is a water-filled balloon; the skin represents the cell membrane, the water represents the cell solution. Suspended in this water-filled balloon are numerous smaller water-filled balloons, representing the organelles with their own membranes and organelle solutions. The transporters would appear as small beads, scattered across and transcending the balloon's skin, their color and shape signifying transport specificity.

HOW DOES THE CELL RESPOND TO THE ENVIRONMENT?

This finely compartmentalized cell (Fig. 1) is not so different from the cells that make up our bodies (Lehninger 1982). It can work independently, but *must* keep in step with other cells if the organism is to function properly.

Seedling Response to Environmental Signals

The signals to which the seedling responds are represented by the chemical and physical characteristics of its immediate environment--water, light, temperature, atmosphere, soil chemistry and structure, wind, mechanical disturbance, etc. (Kozlowski 1979; Levitt 1980a,b). These factors inform the seedling of minute-to-minute changes in the environment, so that it can continually adjust and maintain efficient daily operation. They also provide early warning of impending seasonal trends in the environment, and allow the seedling to prepare for major shifts in climate. The seedling has evolved to the point at which it can receive the appropriate signals and deal with them internally, subsequently adjusting to and tolerating, within limits, extreme climatic events.

Coordination within the organism is mediated by cell regulators. These regulators respond to environmental signals and facilitate the physiological and morphological changes that enable the seedling to cope with its dynamic environment. Cell regulators that respond to specific qualitative and quantitative aspects of environmental cues and are most sensitive to stress include membranes, proteins, DNA, and pigments. Figure 2 shows how these regulators, along with hormones and secondary messengers, fit into a signal/response pathway.

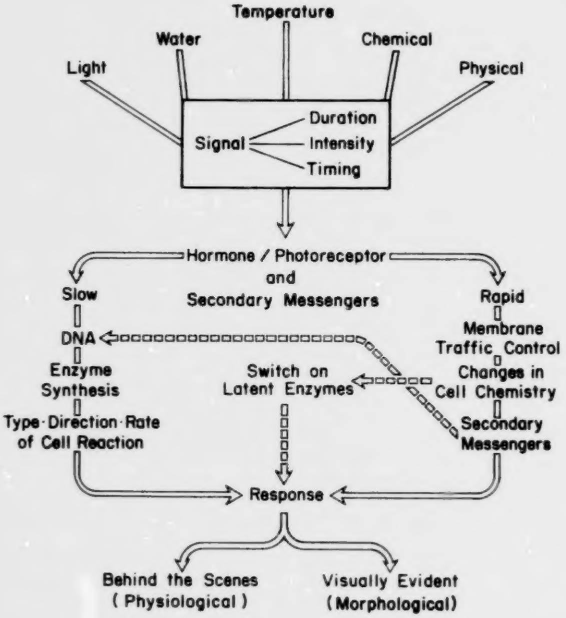
Temperature
Water
Chemical
Light
Physical
Signal
Duration
Intensity
Timing
Hormone / Photoreceptor
and
Secondary Messengers
Slow
Rapid
DNA
Membrane
Traffic Control
Enzyme
Synthesis
Switch on
Latent Enzymes
Changes in
Cell Chemistry
Type·Direction·Rate
of Cell Reaction
Secondary
Messengers
Response
Behind the Scenes
(Physiological)
Visually Evident
(Morphological)

Figure 2. The signal/response pathway depicts major events that are likely to occur as a seedling responds to its environment.

Manipulation of seedlings between lifting and planting greatly increases exposure to stress. Since stress triggers metabolic responses that override or compete with development and growth metabolism, the seedling can suffer a setback (Hoque 1982, Bloom et al. 1985, Bazzaz et al. 1987). The result is a delay in achieving developmental goals, such as seed maturation, acclimation to frost, development of leaf primordia, etc. (Poljakoff-Mayber 1981, DeYoe and MacDonald 1987).

The Role of Stress-sensitive Cell Regulators

Increased understanding of the regulators' role, their sensitivity to stress and the impact of setbacks on survival and growth potential is an important step toward prevention of stress-induced growth loss.

The *membrane* is responsible for cell compartmentalization, mediation of traffic flow within and between cells, and facilitation of energy production (Singer 1974, Eisenman 1987). As "traffic controller", the membrane regulates what goes in and out of the cell or organelle. Transport specificity is achieved by protein transporters embedded in the membrane. These transporters help coordinate the flow of ions, solutes, and cell regulators in response to external and internal cues. Each transporter is responsible for a specific compound or class of compounds. When membrane permeability is altered the changes in cell or organelle chemistry can have a pronounced effect on the direction of cellular metabolism (Helper and Wayne 1985, Berridge 1987).

Pigments are photoreceptors, responsible for capturing light energy (Ninnemann 1980, Smith 1982). The fate of this energy depends on the absorbing pigment. The photoreceptors responsible for capturing light energy to do seedling work include the photosynthetic pigment, chlorophyll, and the photomorphogenic pigments, phytochrome, the carotenoids, and the flavins. Chlorophyll absorbs light that is converted to chemical energy the plant can use to produce food and metabolic substrates. The photomorphogenic pigments use the energy in light to initiate a variety of developmental processes, such as stomatal opening, dormancy induction, flowering, cuticle formation, etc., which are part of gene-related action[4]. Hormones and/or secondary messengers act as mediators in most of these processes (Fig. 2) (Sachs and Tuan-Hua 1986).

Pigment destruction reduces or eliminates absorption of the light signal needed to drive these and other processes (Caldwell 1981, Powles 1984).

Messages arriving at the nucleus are translated by DNA into language that the plant understands. Loss of DNA integrity results in production of nonsense words or phrases, or no response at all (Lehninger 1982, Kuhlemeir et al. 1987).

The words or phrases generated by DNA are in the form of special proteins called *enzymes* (Lehninger 1982, Cech 1986, Kuhlemeir et al. 1987). Enzymes provide the vocabulary the cell needs to determine what has to be accomplished metabolically. Enzymes work individually or in series, catalyzing cellular reactions that convert substrates into products[5]. The culmination of an enzyme-mediated process, which can be long and arduous, is expressed physiologically (by mobilization of food reserves, nutrient reallocation, cell membrane adjustments, etc.) or morphologically (by wax deposition, leaf coloration, bud burst, lenticel development, etc.).

It should be evident by now that each of these sensitive cell regulators plays an integral part in the normal business of the cell (Fig. 2). If the activity of any one is impaired, the whole system suffers. (How many links on your bicycle chain need to break to enhance the thrill of your downhill ride?)

WHAT ARE THE IMPACTS OF STRESS AT THE CELLULAR LEVEL?

Healthy seedlings stay in tune with their surroundings, shifting as often as is necessary to maintain balance, both physiologically and morphologically. Environmental signals that register as "stress" set in motion a number of cellular responses, some designed to warn adjacent cells/tissues of impending disaster, others responsible for cellular adjustment and/or repair. Although many of the pieces of the stress puzzle await discovery, one thing is certain--stress is an expensive process, both biologically and economically (Larcher 1983, Bloom et al. 1985, Chapin et al. 1987). The use of the seedling's resource pool for adjustment and repair limits the availability of resources for development and growth. If stress-induced delays occur during critical developmental transitions (dormancy induction, frost hardening or dehardening, flowering, bud flush, spring root growth, etc.), the risk of planting failure, and its associated costs, will be high.

Cell Response to Temperature Extremes

Needle, bud and stem tissues of temperate species adjust quickly at the cellular level to daily and seasonal temperature variation (Levitt 1980a, Sakai and Larcher 1987). These adjustments help ensure maintenance of metabolic integrity. This is important because enzymes and DNA function optimally within a relatively narrow temperature range. Outside this range, activity declines. Membrane chemistry is also closely linked to temperature, continually adjusting to retain permeability by maintaining a constant viscosity (Chapman 1975).

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[4] The DNA molecule is composed of hundreds of genes which, individually or in small groups, code for synthesis of a specific enzyme.

[5] Substrate-to-product conversions: the synthesis of starch (product) from thousands of glucose molecules (substrate), or breakdown of protein (substrate) into hundreds of amino acid molecules (products).

Root tissues acclimate, but to a lesser degree than aboveground tissues (Levitt 1980a, Lindstrom 1986). Since the soil environment is buffered against fluctuation and/or extremes in temperature, cellular adjustments in roots are limited and sluggish. Consequently, root tissues are very susceptible to damage between lifting and planting; they are like fish out of water.

High temperatures weaken the structure of DNA and enzymes, causing them to denature (unravel) (Tanford 1961, Raison et al. 1981, Teeri 1981). Activity declines or is lost. Cooling may reverse this action (Fig. 3). If temperatures exceed 55°C, these cell regulators are destroyed and the cell/tissue dies. You actually observe protein denaturation every time you fry an egg--the translucent portion turns white.

Mild freezing temperatures cause ice to form between cells and in the cell wall (Fig. 4). Ice has a very low vapor pressure, not unlike the air in the desert on a hot summer day. Consequently, water in the cells that is not bound tightly to solutes or membrane surfaces is pulled from the cell towards the growing ice crystals. This dehydrates the cell (Steponkus 1984, Sakai and Larcher 1987).

Cell dehydration is caused by loss of water from the cell/organelle solution. When this occurs the solution becomes concentrated, changing its chemical character. Ions and/or solutes that were once "friendly" may now limit the catalytic activity of enzymes, or stiffen the membrane, altering its ability to regulate traffic flow or mediate energy production.

The impact of "freeze desiccation" on cell regulators is analogous to that caused by drought stress (Fig. 4) (Siminovitch and Cloutier 1983). Further, just as fall rains allow rehydration of cells desiccated by drought, *slow* thawing allows meltwater from ice crystals to reenter the cells. I emphasize the word "slow" because membranes require time to adjust to temperature change (Steponkus 1984).

Seasonal *freeze/thaw events* in spring and fall, or during storage and transit, can be devastating if seedlings are not sufficiently cold-hardy (DeYoe and Brown 1979, Oquist and Martin 1986, Sakai and Larcher 1987). Damage is typically associated with tissue death that results from loss of membrane integrity. Have you ever handled a head of lettuce after it has been frozen and thawed?

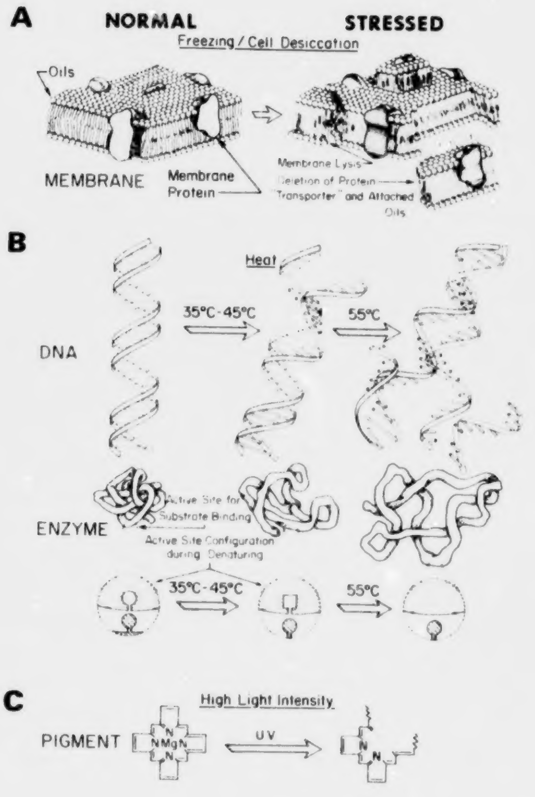
A
NORMAL
STRESSED
Freezing / Cell Desiccation
Oils
MEMBRANE
Membrane Protein
Membrane Lysis
Deletion of Protein "Transporter" and Attached Oils
B
Heat
35°C-45°C
55°C
DNA
ENZYME
Active Site for Substrate Binding
Active Site Configuration during Denaturing
35°C-45°C
55°C
C
High Light Intensity
PIGMENT
NMgN
N
UV

Figure 3. Response of sensitive cell regulators to stress.

a. Freezing--Membranes: The membrane is a bilayer of fatty acids, with a texture similar to that of a film of oil. Like any oil, as temperatures decrease, the membrane becomes more viscous, and eventually solidifies. At this point, or during thawing, the membrane cracks, cellular integrity is lost, and the cell dies.

b. Heat--DNA and Enzymes: The intricate, three-dimensional structure of DNA and all enzymes provides the specificity required for activity. Heat weakens internal bonding, causing unraveling and loss of activity.

c. Light--Pigments (DNA and Enzymes): The energy of ultra-violet and blue light can be sufficiently high to rupture chemical bonding between elements of a molecule. Note the nutrient requirement of the chlorophyll molecule for magnesium (Mg).

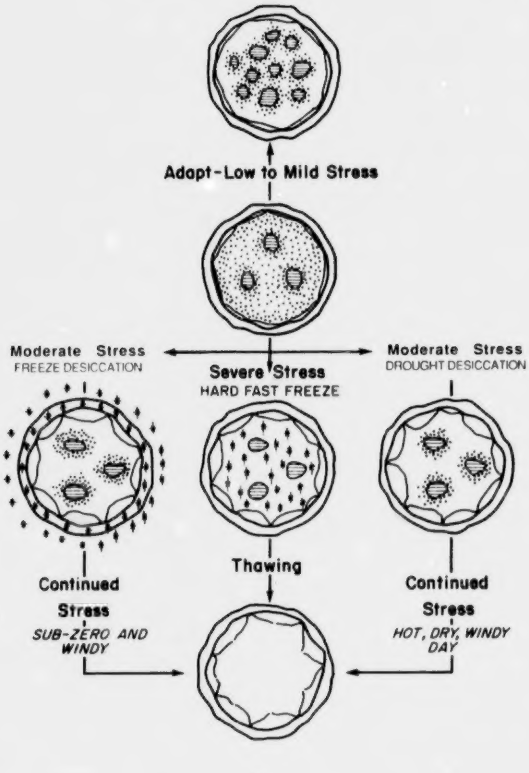

Figure 4. Response of the cell to desiccation stress: Cells adapt to desiccating conditions by minimizing water loss (osmotic adjustment). Desiccation stress caused by freezing, or drought, reduces cell volume and concentrates the cell solution. If stress is too severe, membrane lysis will occur, killing the cell. (∴) = water molecules, (*) = ice crystals

When *severe freezing* reduces temperatures below the cold hardiness threshold of the seedling tissues, whether the bud, the roots, or the stem, the cell solution crystalizes. Membrane rupture occurs and the cell contents are released during thawing (Fig. 3a and 4). Different tissues have different degrees of coldhardiness and the tolerance of one may vary seasonally in relation to another (Tinus 1986). Consequently, the tissue with the least tolerance at a particular time may dictate the fate of the seedling. Needles and buds of Douglas-fir can be hardy at temperatures as low as -15°C, while stems are killed at -7°C, or less, depending on cultural treatment (DeYoe and MacDonald 1987).

Cells avoid freezing by deep supercooling (Burke et al. 1976, Sakai and Larcher 1987) or by adjusting their solute/water balance (osmotic adjustment) (Borowitzka 1981, Siminovitch and Cloutier 1983). Deep supercooling physically prevents ice crystal entry by impeding intracellular ice nucleation and by blocking seeding of extracellular ice via the cell membrane and wax-impregnated cell walls of certain tissue types (buds, xylem rays, and xylem parenchyma). The small, compact character of the cells within these tissue types further inhibits ice nucleation until very low temperatures are reached (-20°C to -40°C, depending on species and/or origin) (Burke et al. 1976).

Adjusting solute/water balance involves increasing the availability of solutes capable of tightly binding water so that losses are minimized. A portion of cell water must be lost quickly to prevent formation of intracellular ice. Excessive water loss must be prevented. In essence, the cell is striving to maintain sufficient turgor[6] to drive developmental processes by minimizing water loss (Tanford 1961, Levitt 1980b, Borowitzka 1981). Water is held so tightly by new solutes that it cannot be pulled away by the evaporative (low vapor pressure) demands of extracellular ice (or hot, dry air in summer) (Fig. 4). Changes in the membrane that facilitate release of water and entry of solutes occur simultaneously and are critical to success (Chapman 1975, Steponkus 1984).

Metabolically, these adaptive processes are expensive, requiring considerable energy, substrate, and time to prepare the seedling to survive temperature extremes (Bloom et al. 1985, Gale and Zeroni 1985). Improper culture and handling practices force seedlings to waste valuable resources on numerous, abundant stresses that can be avoided more easily and at lower cost than stresses inherent to microsites on forest plantations.

Cellular Response to Extremes in Moisture Status

Shifts in cell/organelle pH (acidity) that occur during dehydration are common. Since DNA and many proteins (enzymes, membrane transporters, etc.) function optimally within a fairly narrow pH range, the effects can be dramatic (Smith and Raven 1979, Lehninger 1982). Although dehydration-induced shifts in pH or ionic strength reduce the activity of existing enzymes, the activation or synthesis of adjustment and repair enzymes will occur

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[6] When the cell membrane is snug against the cell wall, the cell is at full turgor. As the cell dehydrates, the membrane pulls away from the wall. Loss of protoplast (cell without the wall) volume and increased solution concentration reduce activity of cell regulators. Turgor is maintained by osmotic adjustment (Fig. 4), or by loosening of the wall fibers so that it can collapse with the shrinking protoplast.

(Adams and Rinne 1982, Sachs and Tuan-Hua 1986). However, if dehydration stress is severe, the membrane may rip as it becomes more rigid or as it pulls away from the cell wall during water loss (Fig. 3a and 4). The result is cell death.

Seedlings survive drought, at the cellular level, in much the same way that they tolerate freeze desiccation, by adjusting their solute/water balance (Siminovitch and Cloutier 1983, Morgan 1984) (Fig. 4). Water loss is minimized by the production of solutes with high water-binding capacity. This helps keep the cell turgid and the membrane tight against the cell wall, both of which are necessary to minimize loss of metabolic activity caused by the effects of dehydration on the cell solution. Turgor pressure can also be maintained by relaxing the cell wall as water is lost (Jones et al. 1981, Teskey and Hinckley 1986).

Seedlings may also expend considerable energy and substrates in creating morphological features that reduce desiccation (Levitt 1980b, Turner and Kramer 1981). Expansive root systems, heavy wax deposits on leaves or in stomatal cavities, and orientation of needles toward the light are a few mechanisms used to avoid cellular dehydration.

"Flooding" refers to waterlogging of plant roots and describes the depletion of oxygen in water caused by microbes and plant roots. Oxygen is required for aerobic respiration in all living cells. Oxygen depletion shifts respiration from an aerobic to an anaerobic mode. Cells continue to use food reserves, but the major products now are heat and substances that are potentially disruptive to the cell (Kimmerer and Kozlowski 1982, Kozlowski 1984). Several of these substances are capable of disrupting the permeability of cellular membranes and altering enzyme activity. If you have ever hyperventilated when excited, or experienced muscle cramps while exercising, then you know what it feels like to be short of oxygen.

Visually, oxygen depletion is expressed by needle and/or stem epinasty (swirling or twisting) and needle yellowing. This is followed by tip dieback and crown desiccation as root mortality increases (Kozlowski 1984, Langerud and Sanvik 1987). Have you ever watched an overwatered house plant become curly and crispy?

Seedlings adjust to oxygen depletion by using both morphological and physiological strategies (Kozlowski 1984). Morphological adaptations include the formation and/or swelling of lenticels, adventitious root production on submerged portions of the stem, and development of aerenchyma tissue (which permits freer movement of gases in stems). These strategies avoid oxygen deficiency by facilitating oxygen transport to root tips to maintain respiration, and stimulate uptake of water and nutrients for new root tip growth.

Physiological adaptations to oxygen deficiency help shift cell metabolism toward alternative pathways of energy production and/or conservation. The focus on energy is essential, for it buys the seedling time to make the "energy-expensive" structural adjustments needed to increase oxygen access.

Cellular Response to Physical Abuse

Physical stresses include wounding, compression (squeezing), tension (stretching),

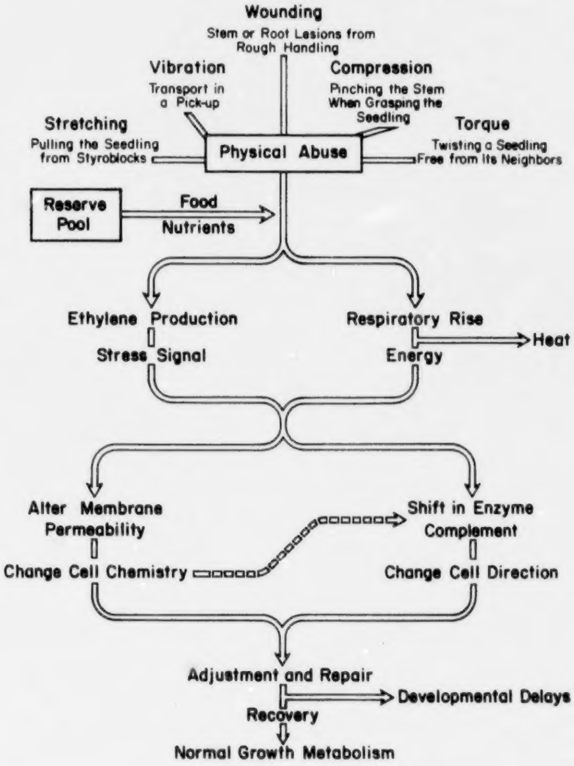
Wounding
Stem or Root Lesions from Rough Handling
Vibration
Transport in a Pick-up
Compression
Pinching the Stem When Grasping the Seedling
Stretching
Pulling the Seedling from Styroblocks
Physical Abuse
Torque
Twisting a Seedling Free from its Neighbors
Reserve Pool
Food
Nutrients
Ethylene Production
Stress Signal
Respiratory Rise
Energy
Heat
Alter Membrane Permeability
Change Cell Chemistry
Shift in Enzyme Complement
Change Cell Direction
Adjustment and Repair
Developmental Delays
Recovery
Normal Growth Metabolism

Figure 5. Response of the cell to physical abuse. The seedling is quite sensitive to physical stimuli. Each disturbance triggers a response. A sequence of physical stresses can have cumulative effects, particularly if insufficient time is allowed for recovery.

torque (twisting), and vibration (impacts) (Jaffe 1980). All trigger a rapid rise in respiration and adjustments in membrane permeability, which facilitate changes in cellular chemistry (Fig. 5). Within a brief period, ethylene[7] levels increase. Ethylene is associated with the transition from developmental to stress metabolism.

The stress/injury response involves adjustments in membrane composition and structure and in the complement of enzymes in cell and organelle solutions (Fig. 5). These modifications help drive adjustment and repair processes. They occur after each physical stress event, and the effects may be cumulative (Levitt 1980a, b; Kauppi 1984).

Cumulative effects are extremely important between lifting and planting because the probability of multiple stress events is so high, and the seedling is extremely vulnerable. How does a boxer feel after one fight, 20 fights, 100 fights...? Have you ever heard the expression "punch-drunk"?

The metabolic costs of adjustment and repair are high. To complicate matters, the risk of stress is highest between lifting and planting when seedlings are unable to generate the food or attain the nutrient levels needed for rapid recovery. All demands must be met by using a limited pool of stored reserves.

If lift/store/plant regimes are conducted during the period of maximum stress resistance in the winter dormancy cycle, stress to the seedling can be minimized. However, if these operations occur outside the period of high resistance, the risk of stress increases significantly. Although survival may not be affected, growth will be reduced (Kauppi 1984; Tabbush 1986, 1987; Dunsworth 1987).

The period of maximum stress resistance varies with species and origin (Levitt 1980a, b; Tinus 1986). Determining a "stress-resistance window" for each species is the first step in identifying lift/store/plant regimes that will minimize stress to seedlings. Monitoring seedling response between lifting and planting can help target *safe* handling practices.

It is unfortunate that seedlings are not prepared to deal quickly and specifically with physical abuse. But how could Mother Nature have known about the hazards between lifting and planting during her evolutionary work with the tree?

Cellular Response to Light Extremes

Seedlings are rarely exposed to extremes in light intensity or to ultra-violet radiation prior to planting. In nurseries in which exposure to high-energy light does occur, frequent irrigation and fertilization facilitate the adaptations that protect seedlings from damage[8] (Smith 1982). It is a different story for the planted seedling, whose ability to adjust quickly to light conditions can be jeopardized by handling history and confounding site extremes. Consequently, the seedling's ability to cope with the light intensity characteristic of openings, particularly at high elevations, may be reduced.

A subtle but important consideration after planting involves the manner in which other types of stress combine synergistically with high-energy light stress to disrupt cellular function (Caldwell 1981, Powles 1984). This has profound implications for seedlings placed in open clearcuts, particularly if they have experienced improper culture or poor handling, or are not genetically prepared to cope.

Pigments are sensitive to light intensity (Fig. 3c). Exposure of shade needles to high light intensity, or of sun needles to extremes in light intensity, can cause destruction of pigment. This may happen slowly by alteration of the natural balance of pigment turnover so that destruction exceeds synthesis (photobleaching), or quickly by molecular mutilation (photo-oxidation) (Caldwell 1981, Powles 1984).

When light intensity is too low, pigments cannot absorb enough energy to drive associated processes (Boardman 1977). Food production rates decline, respiration increases and tissue starvation ensues. This is what happens to interior crown needles as canopies close in a styroblock or in a forest stand. It can also occur in storage if temperatures do not stay cold.

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[7] Ethylene is a gaseous hormone intimately involved in general stress metabolism. It seems to act as an early warning signal of cell or tissue disruption. Its gaseous nature facilitates rapid dissemination of stress information to adjacent cells and/or tissues. The information plays a role in triggering the shift from development and growth to adjustment and repair.

[8] A question yet to be resolved concerns the consequences of planting seedlings grown in low-elevation nurseries (<200 m) on high-elevation sites (>2000 m). Do low-elevation "signals" adequately prepare seedlings for extremes in light, cold, wind, and desiccation (Tranquillini 1979)?

Response to Extremes in Nutrition

Fortunately, seedlings are normally well nourished when they are lifted. Unless unreasonable demands are placed on seedlings because of stresses encountered between lifting and planting, their nutrient capital is normally sufficient to support survival and growth in the first season. However, if seedling nutrition in the nursery is inadequate, stress after lifting will influence allocation. Because nutrients are an integral part of cell structure and function, depletion of the pool to accommodate stress-induced needs will reduce the accessibility of nutrients for development and growth.

Nutrients are part of the structure of enzymes (nitrogen and sulfur), DNA (nitrogen), membranes (phosphorus and/or sulfur), and pigments (chlorophyll - nitrogen and magnesium, and phytochrome - nitrogen and zinc) (Hewitt and Smith 1975). Furthermore, many enzymes require different nutrients as cofactors to facilitate enzymatic conversion of substrates to products. For example, alpha amalyse requires calcium to assist in the breakdown of starch into sugar. For you potato lovers, the alpha amalyse in human beings requires chloride!

Because nutrients are so important to metabolism and the risks of shortages in nature are so great, conifers have evolved efficient mechanisms to store and/or internally cycle nutrients to permit survival (Larcher 1983, Ingestad and Lund 1986). Seedlings also use the ratio of carbon to nitrogen as an internal signal to establish priorities for growth allocation (poor nutrition - grow roots; low on food - grow crown) and production of chemicals to defend against insect and fungal attack (Bazzaz et al. 1987, Chapin et al. 1987).

ACCOUNTABILITY

Here lies Douglas-fir, only an infant at the time of its demise. Its heritage was noble, its potential value great; how can it be that death came so soon? Certainly I was not responsible!

A seedling out of its natural element is at risk. The added complications of handling, confinement and exposure can be fatal. When mortality occurs, it's not a matter of "who dun' it", it's a matter of who is willing to accept his share of the blame and take steps to ensure that it does not happen again.

There are two factors that are crucial in an assessment of seedling demise in the field: the appearance of the seedling and the time of death. Stress symptoms appear as delayed flushing, bud abortion, bottlebrush needles, needle chlorosis (yellowing), etc. Seedling death is expressed by red, chlorotic, dull green and brittle, or brown tissues. All red, yellow, or green and brittle seedlings eventually turn brown.

Consequently, the time of death becomes very important in an assessment of the cause. Early, frequent surveys in spring are necessary to establish time of death arising from culture and/or handling problems. Results from an October survey are of little use in determining whether a seedling died from poor handling in May or from drought in August. Plantation evaluation must begin early in the growing season, and the results, good or bad, must be communicated to all involved.

WHAT CAN I DO?

Numerous operational practices (Table 1) can trigger a stress response. Each stress event plays a part in reducing seedling vigor, particularly if the events occur so frequently that full recovery from any one stress is disallowed. Even if recovery occurs fairly quickly, the consequences of developmental setbacks may influence future response. Make plans to minimize any stresses over which you have control. Then, for Murphy's sake, make contingency plans!

Numerous publications address seedling care and handling (DeYoe 1986). Use the information they contain to establish your own set of guidelines for safe manipulation of stock. You may be able to help those responsible for stock safety to understand seedlings better from a physiological point of view. After all, until we see things differently, we rarely take steps to change our habits.

HOW DO *YOU* PERCEIVE A SEEDLING NOW?

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PLANTING STOCK SPECIFICATIONS / FOREST MANAGEMENT OPERATIONS: INTERACTIONS ON PRODUCTIVE BOREAL SITES

J.E. Wood
Forestry Officer
Canadian Forestry Service
Great Lakes Forestry Centre
Sault Ste. Marie, Ontario

and

R.A. Campbell[1]
Provincial Herbicide Specialist
Ontario Ministry of Natural Resources
Pest Control Section
Maple, Ontario

Abstract.--Desirable planting stock characteristics for use on fertile boreal forest sites and interactions between planting stock specifications and forest management operations are discussed. The field performance of various coniferous stock types, classes and grades of stock within each type has been found to vary with harvesting techniques, intensity of site preparation, and tending practices. In future, nurserymen may be required to grow stock to "match" both site conditions at time of planting and intensity of management. A systems-based approach to prescribing planting stock specifications is recommended.

Résumé.--L'auteur traite des caractéristiques que doit présenter le matériel de reproduction afin de se prêter à la plantation dans les sites forestiers fertiles des régions boréales et des interactions entre ces caractéristiques et les techniques d'aménagement forestier. Chez les conifères, le rendement de divers types, classes et catégories de matériel varie selon les techniques d'exploitation employées, l'envergure de la préparation des sites et les méthodes d'entretien des plantations. À l'avenir, les pépiniéristes devront peut-être choisir leur matériel de reproduction tant en fonction des conditions du site au moment de la plantation que de l'intensité d'aménagement. Une approche systémique est recommandée pour le choix des caractéristiques du matériel de reproduction.

INTRODUCTION

Numerous authors (e.g., Dobbs 1976; Sutton 1979; Scarratt 1982; McMinn 1982a, 1985a) have referred to the need to "match" coniferous planting stock to site conditions at time of planting. This reference is often made in connection with the suitability of stock for planting on productive sites where competing vegetation threatens seedlings. On these sites, competition for site resources is a primary source of stress for outplants (cf. Grime 1979).

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[1] Present address: c/o Canadian Forestry Service, Great Lakes Forestry Centre, Sault Ste. Marie, Ontario

Generally, within the same stock type, the field performance of large planting stock is superior to that of small planting stock (Dobbs 1976, Scarratt 1982). This is particularly true on fertile sites where competition has not been controlled (McMinn 1985a). As well, there is a strong interrelationship between stock specifications (i.e., stock type and classes and grades of stock within stock type; cf. Reese and Sadreika 1979) and intensity of forest management operations (e.g., harvesting, site preparation, planting and tending). These two factors underlie the need for a matching of planting stock specifications to site productivity and intensity of management. Sutton (1985) has described this as a systems-based approach to forest management.

Information relating planting stock specifications to outplant performance on productive sites is urgently required for two reasons. First, forest management efforts in Ontario are currently being directed toward sites with potentially high fiber production and high expected net return on investment (Teskey 1986). Second, Ontario has recently undergone a rapid expansion of its containerized planting program (Scarratt 1985). The small size of current operational grades of containerized seedlings in relation to conventional bare-root stock places them at greater risk after outplanting.

Desirable planting stock characteristics for planting black spruce *(Picea mariana* [Mill.] B.S.P.) and jack pine *(Pinus banksiana* Lamb.) on productive boreal mixedwood sites and interactions between forest management operations and planting stock specifications are discussed in this paper.

DESIRABLE PLANTING STOCK CHARACTERISTICS FOR PLANTING PRODUCTIVE SITES

After a productive forest site is disturbed, the area is quickly colonized by fast-growing plant species (cf. Grime 1979, Chapin 1983, Mooney and Gulmon 1983). The general pattern of change over time, termed secondary succession, is from annual to perennial herbs, to shrubs and rapidly growing trees, to slowly growing trees and shrubs (Chapin 1983).

Typically, plants capable of early establishment on productive sites have rapid rates of growth both above and below ground (Grime 1979). In the boreal forest, many of these species such as raspberry *(Rubus idaeus* L. var. *strigosus* [Michx.] Maxim.), trembling aspen *(Populus tremuloides* Michx.), grasses, and sedges are of little economic value and can hinder the establishment of conifers by competing for moisture, nutrients, and light. Shading from weeds can also reduce the growth of outplants by lowering temperatures surrounding seedlings, while a thick mat of snow-pressed vegetation can bury seedlings (McMinn 1982b, 1984).

McCormack (1981) rated the establishment potentials of spruce *(Picea* spp.), balsam-fir *(Abies balsamea* [L.] Mill.), and several other early colonizers of forest cutovers in the northeastern United States and in the Atlantic provinces. He found that, in comparison with the more aggressive pioneer species, spruce had the lowest overall establishment potential.

To establish conifer seedlings successfully on productive sites, it is necessary that seedlings express dominance early over competing vegetation (Newton 1981). It is, therefore, highly desirable that conifer seedlings possess the attributes of tall stature and large stem diameter, in order to remain upright when snow flattens surrounding vegetation to the ground, as well as rapid early shoot and root growth to outgrow competing vegetation (cf. Newton 1981; McMinn 1982a, 1982b, 1985a).

FOREST MANAGEMENT PRACTICES

In this section, the interrelationships between forest management operations and planting stock specifications are discussed.

Harvesting

Soil disturbance during the logging operation, as well as the amount and species of vegetation that remain on the site after harvesting, can substantially alter future weed populations and, consequently, the size and early growth requirements of planting stock. In addition, good utilization through the removal of weed trees from the site can increase the net area available for planting as well as facilitate future management operations.

McCormack (1984) pointed out that the removal of prolific hardwood seed sources at time of harvesting can reduce their regeneration potential. In mature jack pine stands, Alm (1971) supports clearcutting, accompanied by a deliberate effort to disturb and destroy as much of the hardwood reproduction and shrub understory as possible, in order to aid future management efforts. Reductions in hardwoods or shrubs as a result of logging will likely be very short-lived. Consequently, it is important to get the area back into production as quickly as possible (ibid.).

Good utilization is also important so that crop trees can be uniformly spaced over the entire cutover. Otherwise, weeds will quickly become established in the unplanted gaps in the regenerating stand. Weeds can then compete with crop trees for resources and can reproduce and spread into the surrounding plantation through seeds or runners. Zasada (1971), in a study comparing tree-length and full-tree harvesting systems in jack pine, reported that 30-40% of the cutover was covered with slash and not available for planting as a result of the tree-length logging system. In the full-tree logging system, only 10% of the area was covered with slash and the total area was available for planting without further site preparation. McCormack (1985) predicts that harvesting trends in the northeastern United States and Atlantic Canada are toward greater utilization.

Severe site disturbances related to harvesting can exacerbate existing weed problems by increasing site resource availability, improving seedbed conditions, stimulating vigorously sprouting species, and increasing soil temperatures which, in turn, can often result in germination of dormant weed seeds.

Improvements in utilization, removal of unmerchantable trees, and reduction of site disturbance are likely to result in higher harvesting costs. However, this will be partially offset by lower costs for planting stock, site preparation, planting and tending.

Site Preparation

Site preparation may be defined as the treatment of a site prior to planting or seeding in order to facilitate the regeneration of that site by the chosen method (Sutton and Tinus 1983). On fertile sites, one of the main objectives of site preparation is to provide a "weed-free window" during which conifer seedlings can become established.

Stock type, and classes and grades of stock within each type, can vary greatly in their response to site preparation (Scarratt 1974; Dobbs 1976; McMinn 1982a, 1985a). For instance, in a study in northern Ontario in which the field performance of two stock types of jack pine in relation to two mechanical site preparation treatments (i.e., Bräcke scarification and Bräcke scarification + mounding) were evaluated, Wood et al. (unpublished data) found a strong relationship between stock type, field performance and intensity of site preparation (Table 1). In general, the smaller paperpot stock benefited relatively more than did the bare-root from the more intensive site preparation provided by mounding.

Dobbs (1976), Newton (1981), McMinn (1985a, 1985b) and others have suggested that there is a potential tradeoff between planting stock size and intensity of site preparation. By using large planting stock it may be possible to reduce the intensity and cost of site preparation.

A delay in planting subsequent to a major site disturbance, particularly harvesting or site preparation, can reduce outplant performance because of the development of competing vegetation (McMinn 1982a, 1982b; Ball and Kolabinski 1986). Preliminary findings from an experiment on a fertile upland site in boreal Ontario (Wood and Campbell, unpublished data) have highlighted the importance of planting crop trees soon after a disturbance (Table 2). In this study, black spruce crop trees were planted for three consecutive years in the same plots. All stock types and grades planted in 1982 had higher survival after three growing seasons than those planted in 1983 or 1984. This example serves to highlight the fact that once a planting site has become fully occupied by weeds it is very difficult to establish a crop of trees without further site preparation (Newton 1981).

Table 1. Mean survival after three growing seasons of 2+0 bare-root and FH408 paperpot jack pine stock planted after no scarification, Bräcke scarification, and Bräcke scarification + mounding (After Wood et al., unpublished data).

Stock type	Control	Bräcke	Bräcke + mounding
		Survival (%)	
2+0 bare-root	70	91	92
FH408 paperpots	33	86	88

Table 2. Survival, after three growing seasons, and third-year total height of two sizes of black spruce FH408 paperpot and 1.5+1.5 bare-root transplants planted over 3 consecutive years on the same plots (after Wood and Campbell, unpublished data).

Planting stock	Year of planting 1982		1983		1984	
	Surv. (%)	Ht (cm)	Surv. (%)	Ht (cm)	Surv. (%)	Ht (cm)
Bare-root (transplants)	96	47	79	57	34	50
Paperpot (large)	92	46	59	37	38	48
Paperpot (small)	77	37	24	24	29	32

It is also clear that the longer planting is delayed, the greater the benefit of larger stock. Survival, after three growing seasons, of bare-root and large paperpot stock planted in 1982 was virtually identical (Table 2). However, among trees planted in 1983, survival of bare-root stock was substantially higher than that of paperpot stock. By 1984, competition was so dense that all stock types had very poor third-year survival. In comparison, bare-root stock planted in 1984 in adjacent chemically site prepared plots had 100% survival after three growing seasons.

The choice of herbicides with which to prepare a planting site chemically may also influence the forest manager's selection of planting stock type. Preliminary observations made in boreal Ontario indicate that conifer tolerance to hexazinone, a promising site preparation herbicide, is related to stock type (Table 3). Bare-root stock was shown to be more tolerant to the chemical than container stock when planted immediately after chemical site preparation. These differences were not, however, reflected in height increment, paperpots performing as well as or better than bare-root stock.

Planting Stock

Seedlings that grow quickly after outplanting have a marked advantage over slower-growing seedlings on productive sites. For this reason, managers often claim that larger seedlings can compete more effectively with above-ground competition than can smaller seedlings. Within the same stock types, there is considerable evidence to support this statement (e.g., Dobbs 1976; Walker and Ball 1981; Scarratt 1982; McMinn 1982a, 1985a). Stock size may even be more important than stock type (cf. Ball and Kolabinski 1986); however, Sutton (1979) states that "...the important thing is not what a tree looks like but how it performs in the field".

In Finland, large planting stock is preferred because of competition from weeds (Haavisto and Jeglum 1984). Spruce is produced in two years in FH608 paperpots, while pine is grown in FH508 paperpots for one year before planting.

Because different stock types commonly grow at different rates after planting (cf. Scarratt 1982, Wood and Dominy 1985, Ball and

Table 3. Survival, two growing seasons after planting, and second-year height increment of black spruce and jack pine bare-root stock and paperpots planted immediately after hexazinone was applied at 4 kg active ingredient/ha (after Wood and Campbell, unpublished data).

Species	Stock type	Survival (%)		Height (cm) increment	
		Herb.	Control	Herb.	Control
black spruce	bare-root (1.5+1.5)	99	100	12	10
	paperpot (FH408)	79	93	15	11
jack pine	bare-root (2+0)	93	91	14	14
	paperpot (FH408)	60	99	17	15

Kolabinski 1986) and also vary in initial mass, the manager should consider these factors in relation to the anticipated weed population. For example, containerized seedlings generally have faster initial growth than bare-root seedlings, although they are initially much smaller (Vyse 1982, Scarratt and Wood 1988). On fertile sites, therefore, seedlings should possess the initial size advantage of bare-root stock as well as the early height growth characteristics of containerized seedlings.

Tending

Large, vigorous planting stock, good harvesting practices and biologically sound site preparation can greatly reduce the impact of weeds on crop trees. However, tending may still be required to control weeds that have germinated or sprouted subsequent to site preparation. At present, the use of herbicides is the most cost-effective means available of controlling competing vegetation (Carrow 1985).

The use of herbicides in tending programs has several implications for planting stock specifications. First, herbicide tolerance can vary with stock type and class. Second, some herbicides cannot be used until seedlings are sufficiently tolerant; in some cases tolerance may not be achieved until the end of the second growing season after outplanting. Third, herbicides can bring about a shift in weed species composition through species selectivity or modification of the site.

Forestry herbicides must be able to control weeds without harming crop trees. McCormack[1] ranked various coniferous regeneration types according to the risk of injury from herbicides. In order of tolerance, he rated established natural regeneration as most tolerant, followed by bare-root transplants, bare-root seedlings, large containerized seedlings, and small containerized seedlings. Bärring (1967) found that when he used a soil-active herbicide, mortality in Norway spruce *(Picea abies* [L.] Karst.) and Scots pine *(Pinus silvestris* L.) was greater in stock planted with its root systems close to the soil surface than in auger planted trees with vertical root systems.

Glyphosate and 2,4-D are currently the only herbicides registered in Ontario for use in conifer tending operations. On productive sites, only glyphosate is effective against the most competitive weed species, namely, raspberry and grass. However, because of poor initial conifer tolerance, glyphosate cannot be applied until conifers have been established for more than one year. Forest managers, therefore, must ensure that planting stock is both large enough and vigorous enough to remain in a healthy condition until released from weed competition. Crop trees must not merely survive this delay in tending but should be sufficiently vigorous when released to take advantage of the increased site resources brought about by weed control (Sutton 1985). Unfortunately, forest tending is often delayed until crop trees have declined in vigor (Anon. 1985).

Both glyphosate and 2,4-D can cause a shift in the composition of weed species (cf. Campbell 1981, Perala 1985). If the invading weeds are more detrimental to the outplants than the existing weeds, then the treatment will be counter-productive. For instance, in a 2-year-old plantation heavily overgrown by raspberry, the manager may prescribe a release treatment with a particular herbicide. However, if the manager fails to recognize that grass is an alternative competitor, capable of invading the site soon after the herbicide treatment, weed control may in fact result in worse competition for the outplants. On the other hand, if the planted seedlings are large enough and vigorous enough to compete with the invading grass, but not with the raspberry, the treatment will be judged a success.

SUMMARY

There is a potential tradeoff between stock size and the manager's ability to suppress weed growth. The best outplant performance, however, is generally achieved by planting large stock with good competitive characteristics and complementing this with effective forest management operations.

Harvesting, site preparation and tending can influence the appropriateness of various stock types and classes and grades within a stock type. In comparison with large planting stock (typically bare-root stock), small planting stock (typically container stock) requires more intensive site preparation.

The amount and species of vegetation that remain on the site subsequent to logging and the degree of site disturbance during the logging operation can substantially alter future weed populations and, consequently, the size and early growth requirements of planting stock. Planting should be carried out as soon as practicable after logging or site preparation so that seedlings can take advantage of the "weed free window", which is often very short.

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[1] McCormack, M.L. Prof. of For. Resour. and Leader, Coop. For. Res. Unit, Univ. of Maine, Orono (pers. comm.)

Herbicides used in tending operations can interact in several ways with planting stock. Tolerance appears to vary with stock specifications. Seedlings also must be sufficiently vigorous when released from weeds to take advantage of any increase in site resource availability.

In future, nurserymen may be called upon by the forest manager to grow stock to "match" not only site conditions at time of planting but also the intensity of management that will be practised. On the other hand, forest managers must recognize the biological and economic constraints under which nurserymen work and, therefore, develop regeneration prescriptions that enable seedlings to achieve their growth potential. It is essential that nurserymen and forest managers work together, using a systems-based approach to forest management, to produce healthy, well stocked plantations.

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CONIFER SEEDLING ESTABLISHMENT ON BOREAL REFORESTATION SITES: ENVIRONMENTAL INFLUENCES AND ECOPHYSIOLOGICAL RESPONSES

S.C. Grossnickle
Research Scientist
Forest Biotechnology Centre
B.C. Research
Vancouver, British Columbia

Abstract.—Environmental extremes on boreal reforestation sites can cause physiological stress in the planted seedlings. Combined measurement of site microclimatic conditions in relation to seedling ecophysiological patterns enables foresters to monitor the establishment process. The author reports on the water relation patterns of jack pine, black spruce and white spruce seedlings in response to environmental conditions typically found on boreal reforestation sites. An understanding of this response will permit foresters to identify suitable species-microsite combinations to improve seedling establishment.

Résumé.—Dans les zones de reboisement des régions boréales, les conditions extrêmes du milieu peuvent exercer des contraintes physiologiques sur les semis. Les forestiers peuvent contrôler l'implantation des semis en surveillant leurs réactions écophysiologiques aux conditions microclimatiques du site. L'auteur étudie les effets des conditions caractéristiques des zones de reboisement dans les régions boréales sur l'état hydrique des semis de pin gris, d'épinette noire et d'épinette blanche, de manière à permettre aux forestiers d'identifier les espèces qui se prêtent aux divers microsites à améliorer l'implantation des semis.

INTRODUCTION

Successful forest regeneration is a silvicultural goal, the attainment of which requires an understanding of a species' physiological response to environmental conditions of the planting site. During establishment, newly planted seedlings are susceptible to environmental stress because of inadequate root and shoot development. In addition, reforestation areas consist of exposed planting sites on which varying soil moisture, extreme microclimatic environments, and competing vegetation can influence seedling establishment. Therefore, ecophysiological monitoring of seedling response patterns to field site conditions can be a means of determining seedling adaptation and establishment success.

The environmental conditions of a reforestation site will influence a seedling's water relation patterns. Seedling stomatal conductance (gwv) is influenced primarily by light, absolute humidity difference between the needles and air (AHD), and the seedling's moisture status (Hinckley et al. 1978). When soil moisture is not limiting, light and AHD are the primary environmental factors that affect gwv (Grossnickle and Reid 1984, 1985; Grossnickle and Blake 1986). Stomatal opening requires full cell turgor (Hsaio 1973), and when soil moisture availability is limited, seedling gwv will be reduced. Photosynthesis is affected by stomatal activity and seedling water status. The stomatal aperture operates to maintain a variable balance between CO_2 uptake, while it restricts seedling water loss (Schulze and Hall 1982). Nonstomatal inhibition of photosynthesis with decreasing seedling water status can also occur (Teskey and Hinckley 1986). Hence, maintaining a proper seedling water balance after outplanting on a reforestation site is important for photosynthesis and subsequent seedling growth.

Specific species differences in the sensitivity of boreal conifer seedlings to field site environmental conditions may affect their potential for successful reforestation of cutover sites. Research studies were conducted over the last few years on bare-root black spruce *(Picea mariana* [Mill.] B.S.P.), white spruce *(Picea glauca* [Moench] Voss), and jack pine *(Pinus banksiana* Lamb.) seedlings to examine their water relation patterns in response to aboveground and belowground environmental conditions. This paper will attempt to synthesize these research findings so that foresters will have a better appreciation of the links among site environmental conditions, seedling water status, and successful seedling establishment.

ATMOSPHERIC CONDITIONS

Evaporative Demand

Evaporative demand, as used in this paper, is the absolute humidity difference between the needle and air (AHD). AHD is based on air temperature and relative humidity around the seedling, and the seedling's needle temperature. The gwv of field-planted boreal conifer seedlings indicates a strong relation with AHD, with increasing AHD resulting in a decrease in gwv (Fig. 1A). Species differences were found, jack pine having the lowest gwv at low AHD, and white spruce the lowest gwv at high AHD. The general relation between stomatal closure of boreal conifer seedlings and increasing AHD is in agreement with the results for other conifers (Hinckley et al. 1978).

Results of field studies of boreal conifer seedlings growing under optimal soil moisture conditions show that changes in seedling xylem pressure potential (Ψx) reflected changes in AHD (Fig. 1B). Over the range of AHD normally recorded on boreal reforestation sites, conifer species showed different Ψx responses, as AHD increased, with the greatest to least seedling moisture stress in black spruce, white spruce and jack pine, respectively.

These differences are due to a number of factors. First, black spruce had the highest gwv across the entire measured range of AHD. The primary control exerted by seedlings over water loss is stomatal and cuticular resistance (i.e., low gwv) at the leaf surface (Hinckley et al. 1978). Second, monitoring of new root development over the growing season showed that, among newly planted bare-root seedlings, jack pine produced the greatest number of new roots, and black spruce the lowest number, with white spruce intermediate between the two (S.C. Grossnickle and T.J. Blake 1985, unpublished data). Work done with bare-root boreal conifer seedlings indicates that greater development of new roots will result in a reduction in seedling water stress (Grossnickle and Blake 1985, Grossnickle 1988a). Thus, boreal conifer seedling water status is a reflection of a seedling's control of evaporative water loss and its ability to take up sufficient water to meet the evaporative conditions found on boreal reforestation sites.

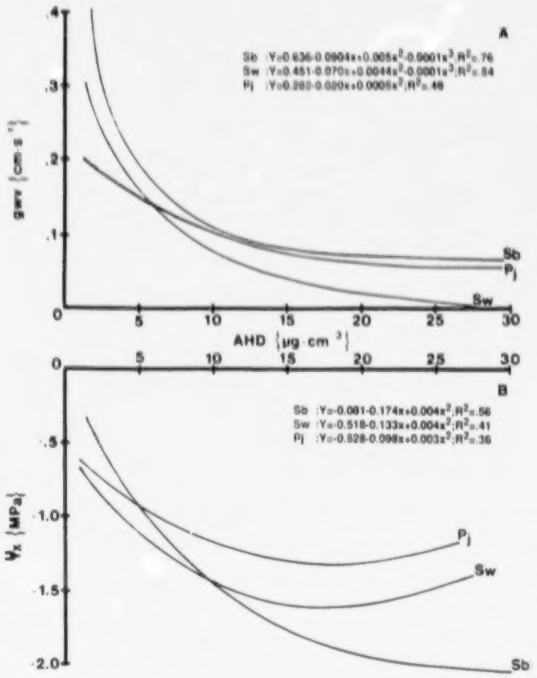

Figure 1. Effect of absolute humidity difference between the needle and air (AHD) on: (A) needle conductance (gwv) and (B) xylem pressure potential (Ψx) for black spruce (Sb), white spruce (Sw), and jack pine (Pj) seedlings growing on a boreal reforestation site. Data points for lines not shown (n = 60 to 70). Adapted from Grossnickle and Blake (1986).

Light

Black spruce, white spruce, and jack pine seedlings on boreal reforestation sites are subjected to varying combinations of aboveground environmental conditions that are continually changing. This makes it difficult to determine the influence of an environmental variable that causes a subtle response in gwv. The influence of photosynthetically active radiation (PAR) and AHD on the stomatal response of white spruce seedlings showed that changes in gwv values were affected by both variables, but that AHD had a greater effect than PAR (Fig. 2). This same type of gwv response to AHD and PAR has been shown in black spruce and jack pine seedlings (Grossnickle and Blake 1986). These findings for boreal conifers concur with results described for a number of conifers in the subalpine ecosystem of the Rocky Mountains, i.e., that the greatest gwv values occurred when AHD values were low and irradiance was high, while low levels of PAR and/or high levels of AHD caused reduction in gwv (Kaufmann 1982, Grossnickle and Reid 1985).

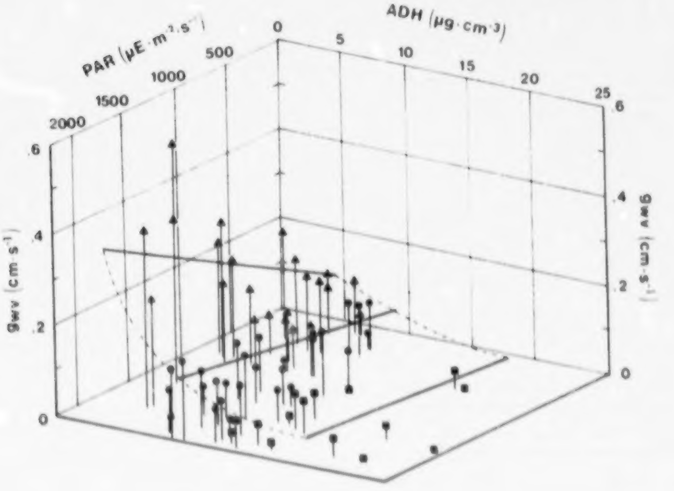

Figure 2. Relationship between needle conductance (gwv), photosynthetically active radiaton (PAR), and absolute humidity difference between the needle and air (AHD) for white spruce seedlings on a boreal reforestation site. The relationship between gwv and PAR is separated into three AHD levels: (1) 0 to 7.5 $\mu g.cm^{-3}$, $y = 0.096 + 0.0002X$, $R^2 = .40$ (▲); (2) 7.51 to 15.0 $\mu g.cm^{-3}$, $y = 0.073$ to $.00003X^2$, $R^2 = .18$ (●); and (3) 15.1 to 25.0 $\mu g.cm^{-3}$, $y = 0.0254$ to $.00002X$, $R^2 = 0.10$ (■). Each point is an average of four seedling measurements. Adapted from Grossnickle and Blake (1986).

Seedlings planted on boreal reforestation sites are exposed to atmospheric conditions atypical of the normal forest stand environment. Atmospheric conditions are normally more extreme on these reforestation sites. The higher evaporative demand that can result reduces gwv, even though light is more than adequate for photosynthesis to occur. As a result, newly planted seedlings can undergo physiological stress (i.e., reduced photosynthesis), which reduces seedling growth and subsequent stand establishment.

SOIL CONDITIONS

Temperature

Low soil temperatures commonly occur during spring planting season in the boreal forest. After seedlings have been field planted on boreal reforestation sites, planting stress can be overcome by rapid new root development. Such development in the field, however, is related to soil temperature and seedling water status.

Research with jack pine and white spruce seedlings shows decreasing gwv with decreasing root temperature (Fig. 3). Reduction in gwv with decreasing root temperatures has also been reported for other conifers (Kaufmann 1975, Running and Reid 1980, Lopushinsky and Kaufmann 1984, Teskey et al. 1984). Seedling Ψx became more negative in both species as root temperature was reduced (Fig. 3). The greater levels of seedling water stress at lower (rather than at higher) soil temperatures result from a greater resistance to water flow through the soil-plant-atmosphere continuum (Grossnickle and Blake 1985, Grossnickle 1988a). Jack pine and white spruce seedling gwv was reduced at lower temperatures even though measured Ψx did not exceed the turgor loss point recorded for these species (Grossnickle 1988b). This reduction in gwv appears to be the primary physiological mechanism for avoiding excessive seedling water stress at low root temperatures (Teskey et al. 1984). Consequently, low root temperatures result in physiological stress, i.e., low gwv, that will cause a reduction in photosynthesis, thereby reducing seedling growth.

Research with bare-root jack pine and white spruce seedlings shows that root growth is reduced at low soil temperatures (Grossnickle and Blake 1985). This confirms the results of other studies on coniferous species (Stone and Schubert 1959, Kaufmann 1977, Nambiar et al. 1979, Grossnickle and Reid 1983). Recent research with bare-root black spruce seedlings has shown that root growth is reduced by low soil temperatures (Grossnickle

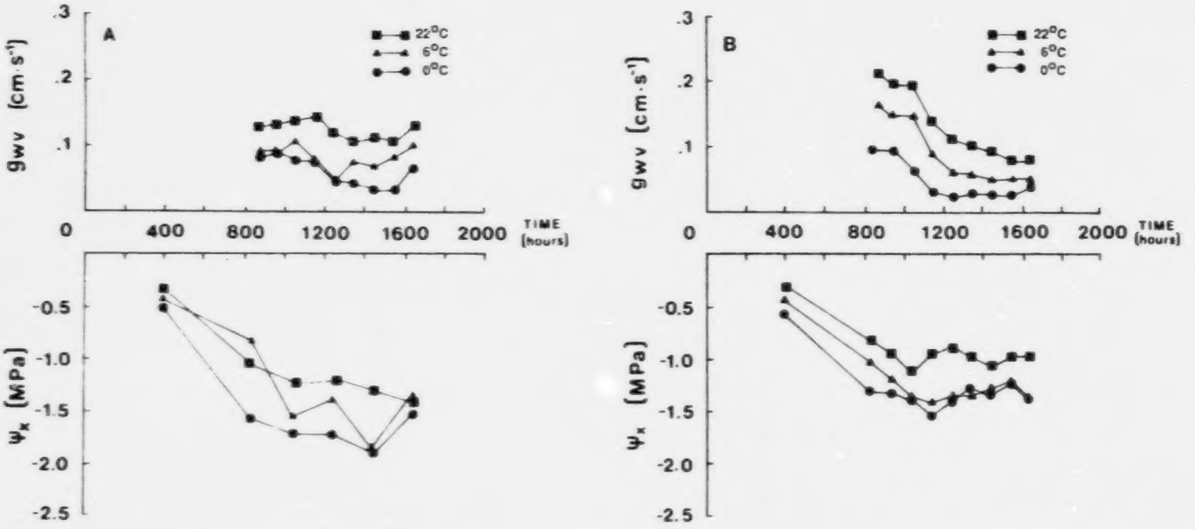

Figure 3. Diurnal patterns of needle conductance (gwv) and xylem pressure potential (Ψx) for jack pine (A) and white spruce (B) seedlings in a controlled greenhouse study at 0(●), 6(▲) and 22 (■)°C root temperatures. Standard errors were typically 0.01 to 0.02 cm s^{-1} for gwv and 0.02 to 0.05 MPa for Ψx. Adapted from Grossnickle (1988a).

1987). Seedlings planted in cold soil lack the new root development required for proper root-soil contact, and seedling water stress results (Grossnickle and Blake 1985, Grossnickle 1988a). The lack of root growth in cold soils also reflects decreased metabolic activity. This negative physiological and morphological response of seedlings planted in cold soils results in slower and possibly reduced seedling establishment.

Drought

During seedling establishment, there is a high probability that boreal conifer seedlings will be exposed to drought conditions (i.e., lack of available soil moisture). Seedling water status is greatly dependent on the amount of available water in the soil and on proper root-soil contact. Hence, any reductions in soil water will be reflected in the water status and subsequent physiological response of seedlings.

Research with bare-root jack pine and white spruce seedlings shows that water stress will affect other physiological processes of seedlings. In a controlled drought study, increasingly negative base Ψx readings resulted in a reduction of maximum gwv readings recorded during daylight measurements (Fig. 4). Research with other conifers shows a strong correlation between increasingly negative base Ψx readings and reduced maximum gwv (Running 1976, 1980).

Measurement of base Ψx indicates the amount of soil water encountered by the seedling and determines the water status at which a seedling begins a daylight period (Hinckley et al. 1978). The decline in base Ψx in jack pine and white spruce seedlings reflected a soil drying condition; the subsequent reduction in maximum gwv reflected the seedling's attempt to maintain adequate water status against increasing drought. Teskey and Hinckley (1986), in a review of the subject, found that decreasing water status can inhibit photosynthesis by stomatal and/or nonstomatal activity. Thus, a restriction of water loss through stomatal closure is an approach that seedlings use to maintain a desirable water status at the expense of reducing their photosynthetic capability.

Root growth in jack pine and white spruce seedlings was also reduced with extended soil drought conditions (Grossnickle, unpublished data). Numerous studies have shown that roots of gymnosperms and angiosperms cease elongation and become inactive at soil Ψ more negative than -0.6 to -0.7 MPa (Leshem 1970, Larson 1980). Day and MacGillivay (1975), working with white spruce seedlings, found little or no root development in seedlings planted in soil with a soil Ψ more negative than -0.6 MPa.

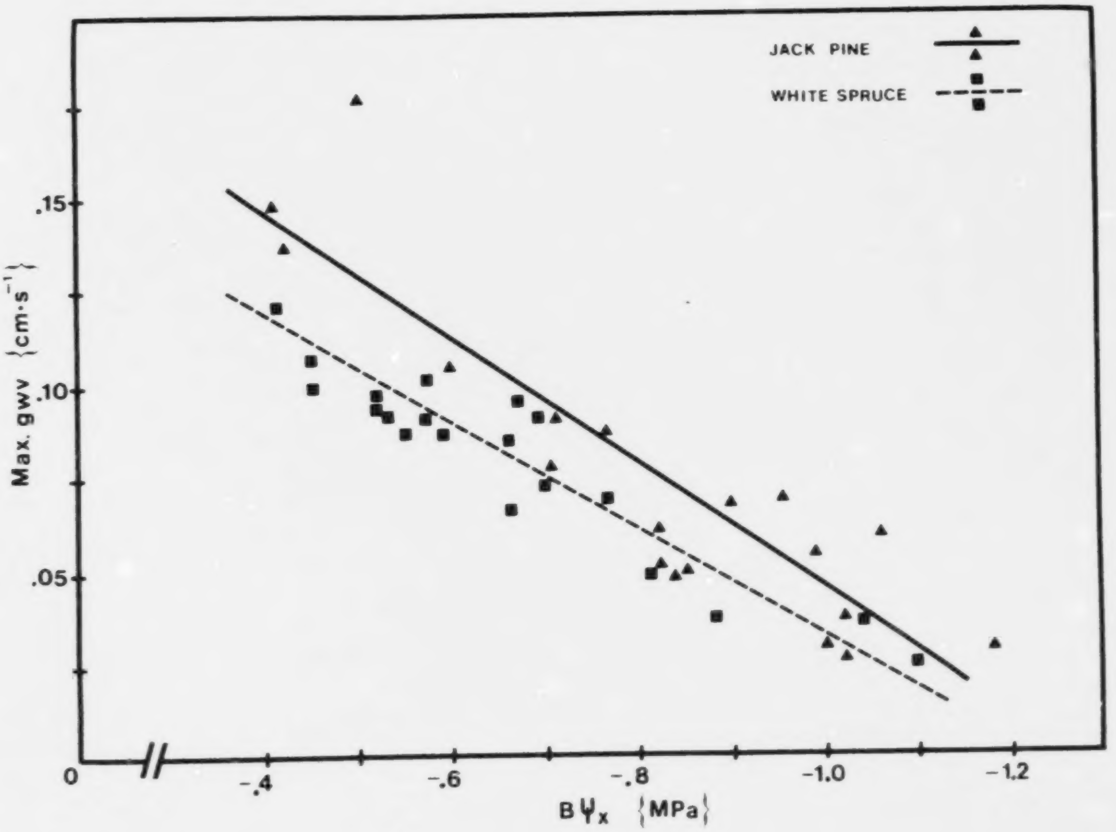

Figure 4. Relation between maximum daylight needle conductance (Max. gwv) and base xylem pressure potential (BΨx) for white spruce and jack pine seedlings in a controlled drought growth chamber study. The regression equations are: white spruce, y = 0.177 - 0.146, R^2 = 0.85 and jack pine, y = 0.214 - 0.170, R^2 = 0.71 (Grossnickle, unpublished data).

During the summer growing season, drought conditions are a potential hazard where forest conifer seedlings have been planted on well drained reforestation sites. These drought conditions will result in seedling physiological stress, reduced seedling growth, and slow stand establishment.

Flooding

An increasing proportion of coniferous lowlands in the boreal forest require reforestation each year. Excessive soil moisture and low soil temperatures are ecological characteristics affecting seedling establishment. Research shows that flooded soils reduce seedling root growth (Kozlowski 1984) and negatively influence seedling water relation patterns (Kozlowski and Pallardy 1984).

In studies of the tolerance of boreal conifers to flooding, black spruce seedlings were found to be more tolerant of flooded soils than were white spruce or jack pine seedlings, but seedling vitality and survival were reduced in all species after prolonged flooding (Ahlgren and Hansen 1957, Zinkan et al. 1974, Levan and Riha 1986). Research with bare-root black spruce and white spruce seedlings resulted in a stressful physiological response (Grossnickle 1987).

In black spruce seedlings just removed from cold storage, gwv was reduced in flooded and non-flooded seedlings (Fig. 5). The longer seedlings were exposed to the soil treatments, however, the more the gwv of non-flooded seedlings increased, while gwv of flooded seedlings remained low. This same gwv response pattern during time out of cold stor-

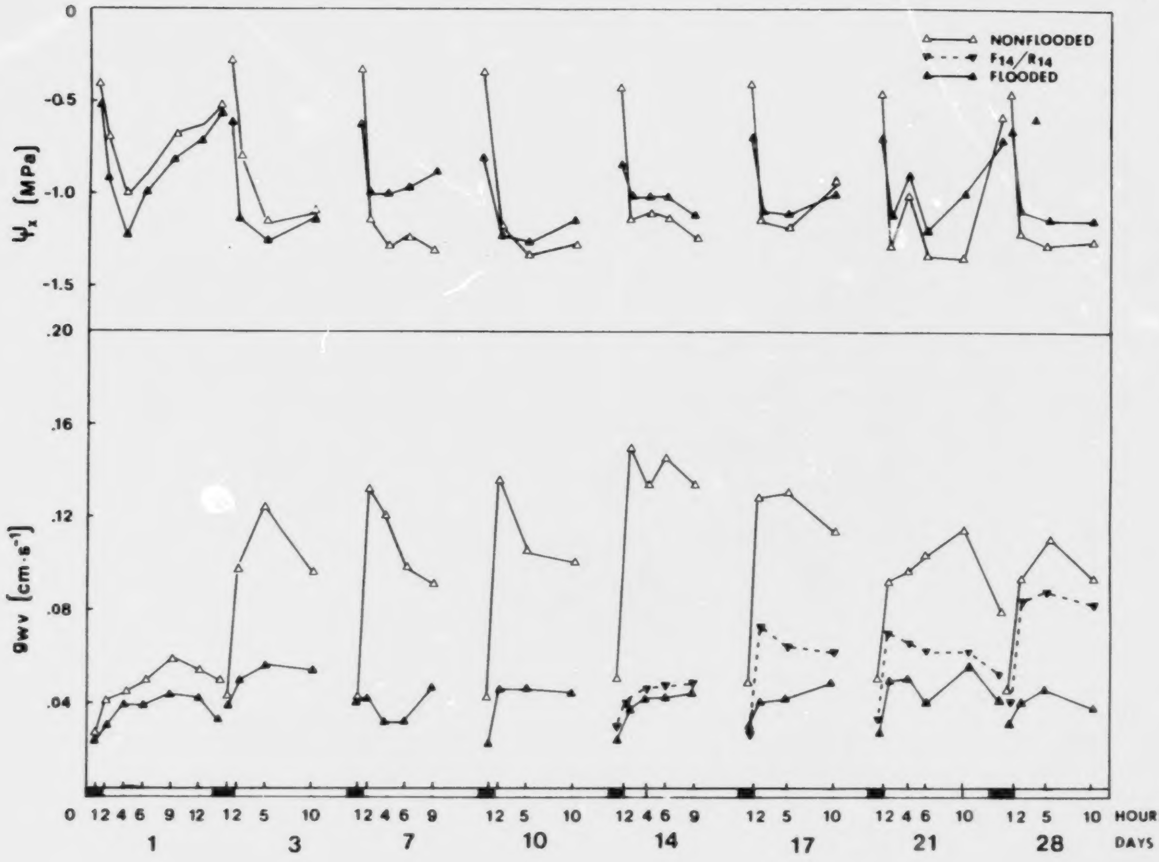

Figure 5. Diurnal patterns of xylem pressure potential (Ψx) and needle conductance (gwv) for black spruce seedlings at a soil temperature of 10°C from day 1 to day 28 after removal from cold storage in a controlled flooding growth chamber study. Heavy dark bars on the horizontal axis represented the beginning of the dark phase; the lights were turned on in between. Measured Ψx values were within 0.05 MPa of the recorded mean and standard error of gwv was typically 0.01 to 0.04 cm s^{-1} (Grossnickle 1987).

age occurred in flooded and non-flooded white spruce seedlings (Grossnickle 1987). Black spruce seedlings released from flooding gradually increased in diurnal gwv. Reduction in daytime transpiration in response to flooding occurred in other coniferous species (Coutts 1981, Levan and Riha 1986). Pezeshki and Chambers (1985a) found that a reduction in gwv in response to flooding resulted in a decrease in photosynthesis. Hence, flooded conditions influence seedling establishment by reducing gwv and subsequently photosynthesis.

Diurnal Ψx for flooded and non-flooded black spruce seedlings showed that flooded seedlings have a more negative diurnal x pattern just after removal from cold storage (Fig. 5). With increased time in the flooding treatment, daytime Ψx measurements were less negative than those of non-flooded seedlings because of the lower gwv measurements of flooded seedlings. These findings confirm results of other researchers (Tang and Kozlowski 1982, Pezeshki and Chambers 1985a, 1985b).

Research with bare-root black spruce and white spruce seedlings showed that flooding resulted in no root growth (Grossnickle 1987). These results are in agreement with those of Zinkan et al. (1974), who found root development in black spruce, white spruce, and jack pine seedlings severely restricted in water cultures with oxygen levels lower than 2.0 ppm. Reduction in seedling root development during flooding indicates that even temporary flooded conditions can influence seedling establishment.

Sites on which boreal conifers are planted sometimes have a high water table during the spring planting season. The root systems of seedlings planted on these sites will be immersed in cold saturated soil. This will cause undesirable water relations patterns, reduced root growth, and possibly, increased mortality.

CONCLUSIONS

Successful seedling establishment on boreal reforestation sites depends on environmental conditions that promote a good seedling water balance. Seedling water stress during field site establishment is usually unavoidable. However, foresters can minimize this stress and improve the physiological status of seedlings with proper silvicultural practices. The following practices should improve the physiological status of seedlings and subsequent field establishment:

1. Improving stock quality: Nursery cultural practices that: a) improve the drought tolerance of seedlings, b) modify the root:shoot ratio so as to improve the ratio of absorbing to transpiring surfaces, c) increase root-growth capacity in field-planted seedlings so as to increase root-soil contact, and d) produce proper cuticle development to reduce unnecessary loss of seedling water.
2. Determining the proper time for planting: Proper determination of the planting window to reduce the constraints of early-season (i.e., saturated soils, low soil temperatures) or late-season (i.e., low soil moisture, high evaporative demands) climatic conditions that can cause an undesirable seedling physiological status.
3. Modifying the site: a) Modifying aboveground environmental conditions by means of alternative harvesting practices (i.e., shelterwood) and microsite shading from natural (i.e., logs or stumps) or man-made (i.e., shade cards) sources on sites that may have high evaporative demands. b) Modifying belowground environmental conditions through proper site preparation to improve soil temperature and moisture conditions.

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THE FIELD PERSPECTIVE

R. Galloway
Regional Forestry Specialist
Northern Region
Ontario Ministry of Natural Resources
Timmins, Ontario

M.F. Squires
Divisional Forester
Lakehead Woodlands Division
Abitibi-Price Inc.
Thunder Bay, Ontario

Abstract.—Field foresters currently must take or leave planting stock offered to them. Matching stock to site is difficult. There are deficiencies in the current production system because of size, bureaucracy and contracting arrangements. Increased flexibility is required to meet field needs. Supply and needs will match only when growers and users deal directly with each other, appreciate one anothers' problems and solve them together.

Résumé.—À l'heure actuelle, les forestiers travaillant sur le terrain doivent accepter ou refuser le matériel de plantation qui leur est offert. Il est difficile de trouver du matériel qui soit approprié à une station. Le système actuel de production comporte certaines faiblesses qui découlent de sa taille, de la bureaucratie et des ententes d'approvisionnement. Il faudra faire preuve d'une plus grande flexibilité pour répondre aux besoins identifiés sur le terrain. L'offre ne répondra à la demande que lorsque les producteurs traiteront directement avec les utilisateurs et que ces deux groupes seront en mesure de prendre conscience de leurs problèmes réciproques et de les résoudre ensemble.

INTRODUCTION

The boreal forest can be regenerated in a variety of ways:

a) Naturally:

  i) by accepting what nature provides, if anything;

  ii) by harvesting to assist nature in regenerating the species we desire.

b) Artificially:

  i) by altering site and stand conditions to take advantage of natural seed distribution;

  ii) by altering site and stand conditions to improve seedbed for seeding of the desired species;

  iii) by altering site and stand conditions and seeding or planting trees of the desired species at the desired spacing.

All areas regenerate eventually to some species. As we increase the intensity of management, costs and results increase accordingly. Planting, therefore, should be done only on sites on which the objective is to increase yield and quality of the desired species within a defined time.

In view of this objective, foresters should not accept substandard planting stock that will have poor survival and growth. Unfortunately, we are all guilty of accepting such stock and we insist on planting the "green count" even though the trees are substandard.

The field perspective on nursery practices is that there are deficiencies that affect the survival and growth of outplanted stock. Furthermore, there are different perceptions in different geographic areas. In certain regions the available stock is improving; in others the quality is declining. Even where acceptable stock is being produced, we should strive for improvement.

The 1986 Northern Region Stock Production Development Activity Seminar and the report on the 1987 losses of container stock in Thunder Bay each suggest solutions to problems identified in this paper. Open communication among the end users, growers and Ontario Ministry of Natural Resources (OMNR) personnel is the most important step in attempting to improve deficiencies. A direct link between the end user and the grower is required.

This paper will discuss, from a field perspective, the needs of the field forester, deficiencies in the current system, constraints on growers and improvements required to improve the current system.

IS THE FIELD BEING WELL SERVED?

No! If the field is considered to be the forest created by our planting stock, we are not serving it well. This is not a condemnation of all Crown or private growers or our current bureaucracy but at attempt to highlight specific concerns.

The field receives stock of different quality as climatic and administrative boundaries are crossed. Improvements have been made at certain facilities and problems continue as before at others.

Trees are not available on a site-specific basis. Roy Sutton's (1982) ideal of "fitness for purpose" is far from being realized.

Specific concerns among field foresters are as follows:

1) Stock standards: Valid standards are needed for growing stock and for measuring results in our plantations.

2) Tree allocation: A specific number of trees should be allocated at the outset so that field staff will know how many to anticipate.

3) For certain sites, trees with larger values for certain parameters may be required.

4) Growers must have an appreciation of how their stock and stock handling affect plantation performance.

5) Problems are created when trees are held at a growing facility until they put on extra weight because it is thought that they will bring a better price, whereas in fact, any new growth they achieve is lost during shipping or planting.

6) Large-scale contracting leads to a lack of diversity in stock types. Different sizes and different types of stock (e.g., cold-frame stock) are required.

7) Smaller seed sources in the future, as we begin to produce genetically improved stock, will mean that handling procedures for growers and field staff will change.

None of us is a perfect manager and problems will continue to arise. They will be solved only by a concerted effort on the part of everyone concerned.

STOCK RELATIVE TO SITE?

There is a wide range of forest sites in the boreal forest of Ontario, from deep lowland peats to shallow upland coarse till with underlying bedrock. Included are deep, well drained loam, deep silty to clay moist soils, and deep sandy soils, among others.

Generally, most forest sites considered for planting in northern Ontario can be grouped in three broad categories of fertility and plant competition:

1) rich, moist, fine-textured, shallow-to-deep soils with severe competition problems

2) fresh, very fine sand to loamy soils of moderate-to-high fertility, with light to moderately heavy plant competition

3) wet peat with light-to-heavy plant competition.

Plant competition varies with climatic zone and topography, and in relation to aspect and water table.

Unfortunately, these conditions are not often found in large homogeneous units; they are more often in a heterogeneous mix. It is often impracticable or even impossible to differentiate among the competition classes in advance because of the extreme variation in texture, moisture and plant succession trends on those soils.

This means that, in practical terms, it is necessary to have vigorous stock of higher grades than may be absolutely necessary on all sites. This stock performs adequately in all conditions and performs better than lower grade stock.

Maxim: When in doubt, use better stock.

STOCK GRADING

What is better stock? Opinions vary, even among researchers. However, the customer knows what he wants and sets the standards much as he does when shopping for a good steak or a suit. If the product doesn't meet his standards, he doesn't buy.

This principle has been at work in Ontario for decades in the greenhouse industry for cut flowers and potted flowers, bedding plants, vegetables, and horticultural products in general. It has been at work to a very limited extent for tree seedlings when there are customers other than OMNR.

Consequently, it is reasonable for a customer in need of forest tree seedlings, when looking for a grower, to set his own standards. The standards outlined in Table 1, though unscientifically established, have been developed in this manner. They are based on 10 years of planting experience in northwestern Ontario. The plantations currently boast 90% survival, with four-year-old black spruce meeting rigid free-to-grow (FTG) size standards (not yet subject to the "official" FTG survey). The best plantations on all sites used stock meeting either grade 1 or grade 2. The stock used in the poorest plantations did not meet grade 3.

Physiological conditions were unknown except for those that could be inferred from morphological symptoms, e.g.:

- thick root collar and large buds, active root tips, 2:2 or 3:1 shoot:root ratio and blue-green color--highest vigor
- yellow (chlorotic) foliage, high luster --low vigor
- green but with grey, low-luster cast to foliage--moribund, poor chance of survival
- red tips to terminals and/or laterals, tending to shed needles or possessing very sharp needles--low vigor or dead
- high shoot:root ratio--low vigor and resistance to drought or competition from other vegetation
- no active root tips--dormant or low vigor depending on previous conditioning
- loss of older needles or trend to burgundy color--low vigor

Table 1. Tree seedling specifications to meet "fitness for purpose" on a range of sites in the boreal forest of Ontario.

Approx. grade	Portion of area (%)	Oven-dry weight (mg)	Shoot ht (cm)	Root-collar diam (mm)	Shoot:root ratio
I	30	1,500	20	3	3/1
II	30	750	15	2	3/1
III	40	500	10	1.5	3/1

Note: During field culling, minimum height, minimum root-collar diameter and visual symptoms of damage are the measurements most often used by individual planters. All other measurements are analyzed before shipping at the nursery in a shade area or greenhouse so that stock can be selected for shipping.

PLANTING STOCK ACCEPTED BY FIELD FORESTERS MUST BE "FIT FOR PURPOSE"

The experience of both OMNR and Forest Management Agreement (FMA) field foresters in relaxing rigid standards and accepting below-standard stock, even when the site can accommodate the substandard stock, is that they are inundated with requests to take varieties of grades, mixtures of grades and species that were never considered appropriate to the site. Their acceptance of such stock is seen as proof that they do not know what they want or why they want it, and that all stock produced is useful somewhere. There is the feeling among growers that field foresters should take what they are offered. In this paper we suggest that they leave it. The end users have a right to set stock standards and to demand stock that meets their needs.

STOCK GRADING OR LACK THEREOF

There has been a serious attempt in recent years by at least some FMA holders to match stock to site conditions. In order to succeed they must know what stock they will receive. Some have no knowledge of their future product.

Each fall, it is intended that the FMA holder meet with the District Crown Representative and agree on the specifications and availability of stock. However, our experience in the North Central Region has been that losses are so great the following spring that all stock must be reallocated. The FMA holder receives some of the originally scheduled product, but in order to meet the annual work schedule, he must accept sub-standard stock.

In 1986 and 1987 no stock that met any standard whatsoever was available in certain locations.

Planting contracts are awarded in January or February before the planting season in order to give the contractors the time required to organize their operations. The type of stock and planting location or site are specified in the contract. Stock is allocated by the anticipated grade. In 1987, for example, on the Spruce River Forest in the North Central Region, only approximately two thirds of the stock received had been allocated the previous fall, and less than half was the stock requested for the site. There was an overall shortfall of 18% in numbers allocated, and a short-fall of 32% on the total numbers requested.

The intense effort to reallocate stock after losses occur causes further disruption and leads to chaos. Field staff have to alter their organization plans. Deliveries are mixed; there is uncertainty among contractors that they will have trees tomorrow, distrust is general and morale is poor. Each party feels that the other is being favored in stock transfers.

It would be much more acceptable to make firm allocations in the fall and stick with them in the spring. In that way some districts or FMA holders would experience heavy losses in numbers, but at least they would know that the trees planted would suit the site and grow well. Trees rejected by one party after winter damage is visible could be offered to others, but there should be no change in allocation of undamaged stock. It should go to the party to whom it was originally allocated.

Knowing which trees are theirs in the fall enables users to predict winter survival on the basis of weather and storage, and to make their own adjustments in numbers. It is the adjustments made by others that cause problems. Spruce River Forest can deal with certainties as they appear; it is the surprises that are difficult to handle.

STOCK QUALITY

In the North Central Region, stock available from private growers has been extremely variable since 1984. Abitibi-Price has been unable to obtain sufficient stock to meet its minimum specifications in any year since then. Much of the stock accepted barely meets specifications one year after outplanting.

In 1983 and 1984, growers were single-cropping and exceeded even optimum size specifications (Table 2). It is readily acknowledged that these specifications are elementary and do not cover the physiological conditions of seedlings. However, visual symptoms as already described have been found to be fairly reliable indicators of survival and growth potential. Generally, if seedlings meet these size specifications and have a 3:1 shoot:root ratio, they are able to survive and grow on all but a third of our area (i.e., that portion on which competition is extremely heavy). Even here, with expensive chemical site preparation or tending, we have had success in some locations.

CURRENT STOCK VS. OVERWINTERED STOCK

Stock produced as a current crop, even if it meets specifications, does not perform as well as overwintered stock. Survival is lower

Table 2. Standards for container stock, 1981-1985.

Species: black spruce

Container: paperpot FH 408

	Minimum	Optimum
stem height (cm)	10	15
oven-dry weight (mg)	300	500

Note: These standards were lower than those requested by Abitibi-Price, but were negotiated to this level. Even these standards were seen by some members of the negotiating committee to be impossible in greenhouses in northern Ontario. They were exceeded, however, in 1982 by two growers on private contract to Abitibi-Price, and by at least three growers for OMNR for delivery to Abitibi-Price in 1983 and 1984.

(Stanclik 1986). On FMA number 500700, current-stock black spruce that surpassed specifications when planted in July 1982 is visibly shorter than overwintered stock that also exceeded specifications but was planted in 1983 and 1984. Both the 1983 and the 1984 products met technical FTG standards in 1987, i.e., 40% stocking of 4-m^2 quadrants with trees 1 m tall, essentially free of competing vegetation (no FTG surveys yet completed or confirmed by OMNR).

The 1983 and 1984 plantations of overwintered black spruce in FH 408 paper pots in most cases will meet Abitibi-Price's objective on FMA 500800, i.e., they will reach FTG status in five years.

Few of the plantations established in 1985 or later with small stock below optimum standards exhibit the vigor necessary to reach FTG status in five years. Some may take 10 years, and some even 15 years, because of lower seedling vigor and intense competition.

PRECONDITIONING

The condition of 1985-1987 container stock varied greatly by the time it reached the field. In some cases the tops met specifications, but the root systems were very small. In others the tops met height specifications but not weight specifications. Still others had their tops and roots damaged by frost or winter drying. Finally, there was overwintered stock in an advanced stage of flushing.

Seedlings need prestressing during the greenhouse growing period so that they can handle stress more readily when they are stored outside or after they are outplanted (Blake 1986).

Because planting requires a substantial investment, it is essential that the trees be vigorous and ready to grow as soon as they are planted.

HANDLING

Truckloads of container seedlings sometimes arrive in an extremely dry condition if they have not been watered shortly before shipping. On one occasion this occurred with stock in an advanced stage of flushing, and new foliage was wilted. One day after planting the new growth fell off. There is no excuse for such carelessness, and growers should be severely penalized for it. In future, such stock will be returned to the grower by planters at Spruce River Forest.

Bare-root stock that has arrived in an extremely dry condition sometimes appears to have been exposed too long between lifting and packaging. Time and effort spent to ensure that bare-root stock is lifted and packaged without being exposed to a stressful environment is well spent.

DOUBLE CROP SYSTEM

Many growers have had difficulty meeting height specifications primarily because of the narrow time window in which they try to meet both height and size specifications and try to harden off the seedlings properly.

As a result, growers often grow a crop solely to meet height specifications, and compress the time available to develop roots and mass and to harden off properly. Consequently, trees are weak, poorly balanced, and unable to withstand winter drying and early spring drought after outplanting.

LACK OF DIVERSITY IN CONTAINER SIZE AND GROWING TIME

To date there has been a narrow range of container stock types available, usually because of administrative decisions and operational constraints. It should be possible, without too much difficulty and expense, to vary the crops and growing facilities so as to produce a wider range of stock and meet the range of field needs.

The following suggestions are worth examining:

a) Build cold frames to grow black spruce in 508 paperpots or equivalent-sized containers for two years. These will be available for shipping in May of the second year after an April seeding date. Costs will be saved on capitalization and heating requirements would be minimal. This stock should be equal to grade I (Table 1).

b) In existing heated greenhouses, grow a crop of black spruce in 508 paperpots or equivalent containers. Seeding will occur early in March. The trees will be grown inside until 31 May and placed outside or in cold frames to finish growing, harden off, and spend the winter. This stock will be grade II or better. The greenhouses can then be used for growing a jack pine crop in 408 paperpots or equivalent containers to place outside in August and harden off for overwintering.

c) Grow black spruce in existing greenhouses as in (b), but in 408 paperpots or equivalent containers. These trees should be grade II or better.

DO FIELD STAFF RECOGNIZE CONSTRAINTS ON GROWERS ?

We believe that there are no biological constraints on growing the three grades of stock mentioned in Table 1 in containers in northern Ontario. The constraints are all administrative. All of the grades have been grown and can be grown again. The limiting items are container size, time and facilities, as described above.

To date, growers and end users have failed to get together to discuss their problems and needs, and to deal with them in a practicable manner. More flexibility and innovation are essential, both in growing regimes and in administrative arrangements.

Constraints are felt mainly in the contracting process. The contract administrator must be allowed more flexibility so that he can amend the contract where it is deficient, or construct it in the first place so that growers can use their ingenuity to solve their problems and ensure that their crops meet specifications.

The contract must, however, contain incentives to good performance and must protect the administrator from the unethical or incompetent grower.

IMPROVEMENT IN EFFECTIVENESS OF PLANTING STOCK SUPPLY

Open communication among OMNR, the growers and the forest industry is essential. Agreeing to agree before negotiations begin is an important step forward.

The following list indicates areas in which improvements can be made.

1) Closer links need to be established among growers, industry and the Crown. This will allow increased flexibility and coordination among the parties.

2) Direct contracting for stock between the FMA companies and the private growers is needed.

3) Stock production development work should be coordinated by a steering committee of OMNR, private growers and forest industry representatives.

4) Records of stock should be kept from the time it is produced by the grower until it achieves FTG status.

5) Annual meetings should be held by growers, OMNR and forest industry representatives. At these meetings problems with respect to standards and allocations could be addressed.

6) Annual field trips should be planned for growers and end users.

7) Specific field trips should be planned to solve specific problems.

8) Payments for stock should be based on the quality of stock and should depend on the end user's need.

9) There should be more flexibility of stock type.

10) Stock should be graded and sorted in cold storage.

11) It should be accepted that costs will increase if larger stock is required.

12) Costs should be evaluated within the total forest management system rather than as an individual operation.

These ideas and many others will help us to produce the required stock. Supply and needs will match only when growers and end users deal directly with each other, appreciate one another's problems and solve them together.

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PUTTING IT ALL TOGETHER: THE CHALLENGE OF MOUNT ST. HELENS

G.A. Ritchie
Senior Scientist
Biological Sciences Division
Weyerhaeuser Company
Centralia, Washington

Abstract.—*On 18 May 1980, Mount St. Helens in Washington erupted laterally, devastating about 61,000 ha of forest land. Approximately 27,000 ha constituted about 14% of Weyerhaeuser Company's Southwest Washington Tree Farm. Reforestation of these lands required an effort of unprecedented proportions, and was hindered by problems such as deep volcanic ash cover, extreme seedling microenvironments, and sudden unplanned demands for planting stock previously unencountered in reforestation operations. Implementing solutions to these problems necessitated close cooperation among foresters, nurserymen, and researchers. The effort was completed within 5 years and involved planting and growing of more than 17 million bare-root Douglas-fir and noble fir seedlings. Survival has ranged from 85 to 90% across most sites.*

Résumé.—*Le 18 mai 1980, le mont St-Helens, situé dans l'État de Washington, faisait éruption, détruisant 81,000 ha de terres boisées sur son flanc. De cette superficie, environ 27,000 ha formaient 14% de la ferme forestière du sud-ouest de l'État de Washington de la Weyerhaeuser Company. Il a fallu déployer des efforts sans précédent pour reboiser ces terres, opérations entravées par de nombreux problèmes comme la présence d'une épaisse couche de cendres volcaniques, de micro-environnements présentant des conditions extrêmes pour les semis et d'une demande soudaine et imprévisible de matériel de reproduction, jusque-là inconnue pour une opération de reboisement. Les forestiers, les pépiniéristes et les chercheurs ont dû travailler en étroite collaboration pour trouver des solutions à ces problèmes et les mettre en application. La mission a été accomplie en moins de 5 ans; il s'agissait de planter et cultiver plus de 17 millions de plants à racines nues de douglas taxifolié et de sapin noble. Dans la plupart des stations, le taux de survie variait de 85 à 90%.*

INTRODUCTION

Forest regeneration is a complicated and difficult undertaking as has been aptly pointed out by earlier speakers at this Symposium. The regeneration process consists of numerous steps beginning with procurement of seed and ending with successful establishment of a stand of free-to-grow trees of a given species or species mix. Each step requires close coördination and communication among many individuals and organizations involved in the regeneration process. Even under the best conditions, there are opportunities for error at virtually every step of the way. Any one mistake can seriously impede or totally disrupt an expensive regeneration operation. This paper describes a case study of a successful regeneration effort carried out under what may have been the worst possible conditions.

My assignment as the final speaker of the Symposium was, in the words of cochairman Rod Smith, to present "...a forceful conclusion for this symposium illustrating, through case studies of successful operations, what can be achieved when a systems approach is taken, and when all parties concerned communicate and work together".

I can think of no more forceful a conclusion than the eruption of Mount St. Helens. A story perhaps as fascinating as the story of the eruption itself is that of the efforts which followed -- efforts to reforest a landscape devastated in unbelievable proportions. Perhaps my talk, rather than being titled "Putting it all together", should have been titled "Putting it *back* together".

BACKGROUND: WEYERHAEUSER'S SOUTHWEST WASHINGTON TREE FARM

Weyerhaeuser Company's Southwest Washington Tree Farm occupies approximately 185,000 ha in the foothills of southwestern Washington's Cascade Mountain range. It is the major source of raw material for the company's manufacturing complex at Longview, Washington, in which lumber, plywood, veneer, pulp and paper, paperboard, chemicals and newsprint are produced.

The native forest falls within the zone named for its climax species, western hemlock *(Tsuga heterophylla* [Raf.] Sarg.) (Franklin and Dyrness 1973). However, the forest is dominated by the subclimax species coastal Douglas-fir *(Pseudotsuga menziesii* [Mirb.] Franco), noble fir *(Abies procera* Rehd.) and Pacific silver fir *(A. amabilis* [Dougl.] Forbes), the true fir growing generally above 900 m and the Douglas-fir from 900 m to sea level.

The area surrounding the volcano is mountainous, with an elevation ranging from 500 to 1200 m. Annual precipitation is about 200 cm. Forest productivity is relatively high, with Douglas-fir site indices ranging from 30 to 36 m and noble fir from 18 to 30 m on a 50-year base (Winjum 1984).

Mount St. Helens is a stratovolcano. It had erupted previously in the years 1500 and 1800, and periodically between 1831 and 1857 (Crandall and Mullineaux 1978). St. Helens is the youngest of 15 volcanoes in the Cascade range--about 40,000 years (est.). Mount Rainier, by contrast, is believed to be about 1 million years old.

THE ERUPTION

Mount St. Helens began to show signs of renewed volcanic activity in 1979. This activity was manifested in several steam eruptions, formation of two fissures at its summit, and modest ashfalls. At precisely 8:32 p.m. PDT on 18 May 1980, Mount St. Helens exploded in a cataclysmic lateral eruption which was triggered by an earthquake measuring 5.1 on the Richter Scale. The blast sent a plume of steam and ash some 25 km into the air. The speed of the lateral blast approached 200 m/sec and raised surface temperatures to about 300°C for about 15 minutes. All exposed plants and animals were killed instantly. The event changed the height of the summit from 2951 m to 2551 m and vaporized about 2.74 km^3 of mountain and glacier.

The blast, generated by a lateral, rather than the more common vertical, eruption, resulted in extensive ground damage north of the mountain. The "blast zone" on the north side of the volcano lies roughly between two radii, about 160° apart, originating at the volcano (Winjum 1984). One extends 27 km from the volcano in a WNW direction, while the other runs slightly north of east out to about 14 km. The blast zone encompasses a total of about 60,000 ha.

Among the losses were approximately 56 human lives, 221 homes, 12 bridges, 27 km of railroad track, hundreds of kilometres of roads, about 5000 blacktailed deer, 1500 elk, and millions of smaller animals and birds (Winjum 1984).

Losses to Weyerhaeuser Company, apart from forest trees, consisted of 12 logging sites and 10 rock pit operations; about 650 km of roads and bridges; and three non-resident logging camps containing maintenance shops, equipment, transfer stations, 39 rail cars, and 63,000 m^3 of decked logs (Winjum 1984).

DAMAGE TO LAND AND FORESTS

Land immediately northeast of the volcano was covered with ash, mud and debris to a depth of 100 m or more. Mudflows coursed rapidly down the major river valleys, inundating the valleys and destroying everything in their path. On the sides of nearby hills northeast of the crater, all plant cover and soil were blasted away and bedrock was exposed. The entire region was blanketed with gritty volcanic ash, the depth of which varied with distance from the volcano. Depth at 13 km was typically 75 cm, at 19 km it decreased to about 38 cm, and at 27 km it was only about 5 cm.

Forest damage was extensive and spectacular. Within the blast zone all trees were pulverized or blown down like matchsticks. The blast zone was surrounded with an area of "standing dead" timber--trees that were killed by the searing heat but remained standing following the blast. Outside of this zone was a fringe of forests wherein trees were damaged but still living.

In all, approximately 61,000 ha of forest were destroyed, on both public and privately owned lands (Table 1). The greatest forest loss was that incurred by Weyerhaeuser Company--about 27,500 ha, or approximately 14% of the Southwest Washington Tree Farm. This included about 15,000 ha of merchantable timber, much of it valuable old growth containing trees more than 180 cm in diameter. In addition, 10,000 ha of young, precommercial plantations ranging from 1 to 25 years of age were completely destroyed. Total losses of forest and other amenities incurred by Weyerhaeuser Company alone amounted to $66 million on a pre-tax basis (Winjum et al. 1986).

Table 1. Land ownership in the blast zone of Mount St. Helens (modified from Winjum 1984).

Organization	Area (ha) (x 1000)
United States Forest Service	25.9
Washington Department of Natural Resources	4.9
Burlington Northern Timberlands	2.0
Weyerhaeuser Company	27.5
Small individual lots	0.4
Total	60.7

PUTTING IT BACK TOGETHER

It was immediately apparent that Weyerhaeuser had sustained losses of unprecedented proportions and that management plans for the tree farm, indeed for the entire region, needed to be immediately and substantially changed. It was also clear that the recovery effort would require very close coordination and communication among corporate management, tree farm operations, nursery operations and various research groups.

Coordination

On 4 June, forest scientist Dr. J.K. Winjum was named Mount St. Helens Research Coordinator. His responsibilities were, broadly: to work with tree farm and corporate managers to identify key research priorities, to lead and coordinate all related within-company research with the help of a steering committee, to serve as company spokesman with all external agencies involved in forestry research, and to serve as a focus for all inquiries relating to Mount St. Helens forestry research.

Cooperation

On 9 June a team of researchers and operating personnel met to hammer out a list of technological needs for recovery. These included understanding (1) properties of the ashfall, including depth, chemistry, and microclimatology of ash-covered landscapes; (2) health and safety of workers in the blast zone; (3) effect of the abrasive volcanic ash on equipment operation; (4) condition of wood in and around the blast zone in relation to its salvageability; (5) potential for insect and disease buildups in the dead timber and their impact on salvage operations; (6) threat of further damage from floods and mudflows; (7) recovery of natural plant communities; (8) wildlife recovery; (9) forest regeneration; (10) grass establishment and fertilization; (11) the impact on growth of trees in stands immediately surrounding the blast zone; and (12) future forest productivity in the blast zone following regeneration.

Research plans, personnel assignments, and budgets were developed and work began immediately in each of these 12 areas. The remainder of this paper will focus on item 9--forest regeneration.

THE REGENERATION EFFORT

Regenerating the area was in every way a new challenge. A review of the scientific literature revealed that such an operation had no precedent (Stevens et al. 1987); hence, no one could be certain that successful regeneration was even possible.

The first small trial was conducted on 16 June 1980 by research and tree farm personnel, who used about 1,000 each of bare-root Douglas-fir and container noble fir seedlings. This early trial revealed several serious problems. In the first place, the St. Helens ash was essentially devoid of plant nutrients (Moen and McLucas 1981); consequently, the ash had to be scalped before planting so that seedling roots were in contact with mineral soil. Scalping, in turn, caused stem girdling by weevils (*Stremnius* spp.), which tended to concentrate in the scalping holes. (This problem was subsequently solved by planting larger-caliper stock.) In the second place, the ash caused a harsh, extreme microclimate which resulted in severe seedling stress and loss of vigor. In the third place, the areas in which the ash was deepest were highly prone to erosion.

These early research trials generated sufficient information that operational plans could be made for subsequent regeneration activities. These plans called for reestablishment of plantations on about 18,000 ha between 1981 and 1985. The general strategy was to regenerate first the lands that posed the least difficulty (those containing shallow ash, modest amounts of debris), while at the same time continuing research on regeneration of the deep ash sites and site preparing the debris-laden areas. There was a need as well to identify attributes of seedlings capable of surviving in this harsh landscape and to develop plans to produce large quantities of such planting stock.

Full-scale operational regeneration began in February 1981, with seedlings grown at Weyerhaeuser's Mima Forest Nursery near Olympia, Washington. This nursery, one of the largest on the west coast, has an annual production of about 24 million bare-root seedlings, mostly coastal Douglas-fir. Lifting operations are conducted in December, January and February; then stock is stored in freezers at -1°C, where it remains in a dormant condition until it is field planted (Ritchie 1984).

The easiest sites to plant were plantations 1 to 10 years old that were relatively free of heavy ash and debris. These were planted with shovels, the ash layer was scalped and small drainage channels were cut to enable water to drain out of (rather than into) the planting holes. During this first year, seedling supplies were low and stock from adjacent seed zones had to be used. About 2,000 ha were planted in this manner.

More difficult to work with were plantations between 10 and 25 years old, because they were too dense to plant and were impossible to burn since the ground was covered with ash and would not support fire. Hence, this material had to be felled first or crushed before burning. Some slash burns in these areas are larger than 600 ha.

Ash depths of more than 20 cm posed another serious problem. Hand scalping was not feasible in this material because of its excessive weight and planter fatigue. The only method that proved successful was to prepare these sites with a tractor-mounted V-blade. About 1,000 ha were prepared and planted in this way.

Unfortunately, scalping with a V-blade was feasible only on ground with less than 30% slope. Power augers were tried on steeper slopes, but were only marginally successful.

Very deep ash (20-30 cm) posed serious problems. An initial approach employed direct planting in the ash, with subsequent addition of various fertilizer treatments. These trials were not successful.

Planting in 1982 focused on two types of areas: low-elevation, shallow-ash sites (about 1,500 ha) and middle- to high-elevation, deeper-ash sites (about 2,000 ha). The low-elevation sites were planted with Douglas-fir. Little or no site preparation was needed because there had already been extensive salvage logging on these areas. Seedling survival averaged 88%. Douglas-fir and noble fir stock was planted on the mid- to high-elevation sites, respectively, with good success. Although this stock suffered loss of vigor because of winter desiccation aggravated by lack of vegetation on the barren, ash-covered landscapes, survival did approach 90%.

Subsequent activities reached a peak in 1983, when about 5,000 ha were regenerated. By 1984, 2+1 Douglas-fir and noble fir transplant stock from the same seed zone (which had been ordered immediately after the eruption) became available. This stock was planted on some 3,400 ha in 1984 and on an additional 1,600 ha in 1985.

By the end of 1985 the project was essentially completed. In all, about 18,000 ha of new plantations have been established with about 17 million bare-root Douglas-fir and noble fir seedlings. Seedling survival in most of these areas has been better than 85%. Of the remaining 9,000 ha, about 7,000 were traded to the United States Forest Service for inclusion in the Mount St. Helens National Volcanic Monument. A satisfactory method of regenerating the remaining deep ash and mudflow areas has not yet been found, and these areas--comprising about 2,000 ha--will remain unplanted for the forseeable future.

While the list of people who participated either directly or indirectly in this effort is lengthy, several stand out as having made major contributions. Among these are John Keatley, Regional Forester, Jerry Gutzwiler, District Forester, and Richard Ford, Regeneration Forester on the Southwest Washington Tree Farm. Among the researchers were Drs. Jack Winjum, Robert Stevens and Philip Dougherty from the Centralia Research Center, and Alex Dobkowsky, Research Forester stationed on the Tree Farm.

CONCLUSIONS

The success of the operation outlined above can be attributed in large measure to the following factors:

- total commitment of senior managers to provide continued and unwavering support for the effort
- a prevalent atmosphere of urgency, which led to circumvention of red tape and bureaucratic meddling
- immediate organization of a special research-operations task force, whose mission was to do whatever was required to regenerate the devastated area
- a sophisticated and flexible nursery system with the capacity to produce large volumes of high-quality planting stock on very short notice
- close cooperation among nurserymen, field foresters, and researchers in identifying, anticipating and producing needed planting stock
- a strong emphasis on safety, which resulted in no accidents involving time loss during the life of the project
- a corporate resource consisting of a diversity of people and professional disciplines
- near-immediate transfer and implementation of new research information by operating personnel (This was a result of virtually day-to-day contact between researchers and operating people in both nurseries and the field.).

ACKNOWLEDGMENTS

I wish to thank Dr. Jack K. Winjum and Mr. Alex Dobkowski for assistance in compiling information included in this presentation. In addition, Dr. Rex McCullough, Director of Forestry Research, and Mr. George Finger, Western Seeding Production and Tree Improvement Manager, Weyerhaeuser Company, provided reviews and suggestions on preparation of the manuscript.

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PANEL DISCUSSIONS

Moderator: L. F. Riley

"How well are we meeting artificial regeneration objectives, and what needs to be done to improve effectiveness of planting stock production and performance?"

A PRIVATE GROWER'S VIEWPOINT

A.S. Aidelbaum
President
North Gro Development Limited
Kirkland Lake, Ontario

It is rather interesting that the low man on the totem pole goes first. However, I shall not waste any time on formalities, but shall identify immediately the three principal groups involved in forestry in Ontario, outline their responsibilities, and express my concerns about the way in which these responsibilities are being met.

The three groups are the provincial government of Ontario, with its master plan; the timber and pulp industry as the end user and harvester, responsible for reforestation; and the grower, responsible for supplying a product to standard. As links between these groups there are various scientific and administrative bodies. All are motivated by the desire for financial rewards and security.

Before reviewing our success to date in meeting objectives, I think it is essential that each group examine its own objectives carefully. If we have individual concerns, these must be addressed internally. If we have problems related to the other two principals involved, communication with them is essential.

We require a forum for communication so that, once we have identified problems, we can assist one another in solving them. If I may use the present forum (i.e., the Panel Discussion of this year's OFRC symposium) for that purpose, I would like to say that the growers are the newest boys on the block, and we are the least equipped to cope with immediate change, to respond to system shortfalls or to explore and develop new methods.

We are an aggressive, hardworking group, and we have met our original production targets. We are willing to move forward and to accept change. We recognize that vast improvements are going to be necessary in the future, but we have already made seedling production in Ontario an economic reality. We have moved from the "smoke and mirrors" era that preceded ours.

I should like to address a few remarks to the forest industry. The product you want is obtainable, but you must recognize the limitations of the systems now being used. You are the buyer; we recognize that you have the right to set the standards. If you wish to change these standards, you must give us lead time to respond. It requires lead time to adapt to different containers and different parameters. Be realistic about the system we are using now, as we are very close to meeting the standards you have set.

Some of the parameters you set are very realistic, while others are archaic. I think we must establish a data base for more site-specific stock. There may be factors such as loaded nutrients, smaller trees, bigger root collars and larger root volume that will have to be considered in the future.

We require some flexibility in judging crops: there should be on-site foresters who can examine trees and determine whether they are up to standard. If we leave this task to the accountants and statisticians, we will end up producing nondegradable plastic trees on wire coat hangers.

As for the provincial government, your responsibility for supporting the forest industry and the growers is obvious. You are the cooperative broker, and it is up to you to supply scientific advisors. We need scientific advisors to work on projects related to Ontario and local conditions; the sex life of a red pine tree in Colorado is not of much concern to us. Ontario's commitment to the forest as a renewable resource is commendable, and we are impressed. But keep in mind the need for long-term objectives, and the establishment of forums in which all three groups participate.

To both the provincial government and the forest industry I would like to say that motherhood demands responsibility. We have completed our first five-year cycle. The original picture, once large and exciting, is starting to get out of focus, I'm afraid.

I do not want to take time to go into specific problems or to suggest remedies, but I implore you to give us some assurance of stability so that we will be able to develop the best possible tree seedling stock. Let's return to the original process that created this system, and let's establish policy that recognizes that the grower is the "fragile link" in the chain.

You will do well to remember that the spaceships which blow up on the pad are usually built by the lowest bidder.

ONTARIO MINISTRY OF NATURAL RESOURCES BARE-ROOT NURSERY VIEWPOINT

A.J. Campbell
Superintendent
Kemptville Nursery
Kemptville, Ontario

I suppose I represent the old bare-root tradition in nurseries. I'll confine my remarks to southern Ontario nurseries where we grow a combination of transplants and seedlings of approximately 15 conifer species, six hardwood species and five species used to enhance wildlife habitat. I would like to refer to the second part of the question posed to the panel, namely: **"What needs to be done to improve the effectiveness of planting stock production?"** We have grown trees for some 50 years in the old nurseries, but we still don't have all the answers. The first thing we need is a permanent support organization to deal with specific problems while we perform our regular duties of applying the best cultural techniques possible.

I shall describe briefly some of the problems that require attention. The perennial task of controlling weeds is becoming increasingly complicated as we try to reduce labor and intensive hand weeding by using chemical herbicides. Because the field of chemical pesticides is dynamic, we need continuing support in this field. Also, we are faced with an ever-increasing root rot problem, especially in southern Ontario. Root rots have the potential for destroying millions of seedlings per crop year if we do not learn how to combat them or live with them successfully.

We have had support in these areas but it has been sporadic. We need a more permanent support system so that we can improve our effectiveness in producing good-quality stock. There is also the question of stock performance. We have recently produced the first provincial publication on stock quality monitoring, which is very useful when we are measuring morphological qualities of our stock. However, it is weak in the evaluation of physiological qualities, those qualities that we cannot see. A great deal of work must be done on physiological qualities so that we will know when *not* to ship a stock lot because it does not have root growth potential. As well, we have to be able to determine root growth potential so that we can make cultural changes, if necessary, to improve it. Very simply, we may have fine-looking nursery stock that won't grow at all. The primary performance criterion is survival. If stock doesn't survive we will have nothing to work with; hence, we must be able to grow stock with good root growth potential.

These are only a few examples of problems in our bare-root nurseries that need to be dealt with by a permanent support organization.

ONTARIO MINISTRY OF NATURAL RESOURCES FOREST MANAGEMENT VIEWPOINT

G.C. Oldford[1]
Regional Forester
Northern Region
Ontario Ministry of Natural Resources
Timmins, Ontario

After listening to previous speakers Rob Galloway, Mac Squires and Abe Aidelbaum I don't have a lot to add, but I will take the opportunity to talk briefly about what I think needs to be done.

First, I believe that continued success will be dependent largely on good, strong dialogue between the producers of both bare-root and container seedlings and their clients. We're endeavoring to do that.

Second, I believe that we must focus on the type of seedling needed in the field, and make it our objective to produce that type of seedling in the facilities available. We will have to identify needed research and development work so that we can get on with the job.

Third, I believe that the December seminar in Timmins, which dealt with stock performance, accomplished quite a lot. Currently there is an active team of OMNR, industry and private grower professionals addressing the problem and finding solutions.

Fourth, I believe that seminars are an effective vehicle for transferring technology. Action is needed by the industry, by the growers, and by the government to resolve the problems. We need to answer questions about subjects such as freezer storage, the type of container that should be used to grow special types of stock, and the need to match containers to site. A very strong link must be developed between the producers of stock and those who use the seedlings.

At present stock production in Ontario is undergoing changes. Part of the responsibility for stock production is being transferred to the Forest Management Agreement holders. I accept and appreciate Mr. Aidelbaum's concern that the lowest price won't guarantee the best tree but I also say that the highest price doesn't necessarily guarantee the best tree either. We must strive for middle ground. In the midst of change there will be a great deal of concern and frustration, but all parties must be positive and cooperative. To achieve our goals we must innovate, accommodate and be receptive to change, all in a spirit of cooperation.

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[1] Present title and address: Manager, Forest Production Section, Forest Resources Branch, Ontario Ministry of Natural Resources, Toronto, Ontario

ONTARIO MINISTRY OF NATURAL RESOURCES DEVELOPMENT GROUP VIEWPOINT

W.E. Raitanen
Coordinator
Northern Forest Development Group
Ontario Ministry of Natural Resources
Timmins, Ontario

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1) A Statement of Objectives for Early Plantation Performance

The first part of the discussion topic refers to regeneration objectives. A statement of desired objectives is required; otherwise, any performance would be considered satisfactory. The Northern Region of the Ontario Ministry of Natural Resources held a seminar in December 1986 that focused on the issue of stock quality or "fitness for purpose." A steering committee was formed as a result of this seminar to ensure a coordinated approach for the Stock Production Development Activity in the Northern Region. This committee has established early plantation performance objectives by species and by year, for both survival and current annual height increment (Table 1). The intention of the committee is to use these early plantation performance objectives as the basis for directing the Stock Production Development Activity in the Northern Region.

Table 1. Early plantation performance objectives: "fitness for purpose"

		Black spruce	White spruce	Jack pine
Survival (at 5 yr) (%)		85-95	75-85	90-100
Current annual height increment (cm)	yr 1	10	12	15
	yr 2	20	25	30
	yr 3	30	40	50

2) The Need for Feedback

The Northern Region steering committee for the Stock Production Development Activity also recognized the need for comparative trial series to provide feedback on stock standards and early plantation performance. This comprehensive trial series involves the Forest Management Agreements, Crown districts, private growers and nurseries. A correct and proper statistical design is required to provide confidence in the data. The Scientific Advisors are K. McClain, OMNR Research, Thunder Bay for the Client Trial Series and J. Paterson, OMNR Research, Maple for the Growers' Trials.

3) Effectiveness

The second part of the discussion topic deals with effectiveness. This has to do with achieving objectives or measuring what has been accomplished against the objectives set. I would draw your attention to the data set in Figure 1 that represents the current annual height increment in year one for 19 different treatments of black spruce (provided by D. MacMillan of the Swastika Tree Nursery). This Careful Planting Trial, established in 1987, is part of the comprehensive trial series established by the Northern Region.

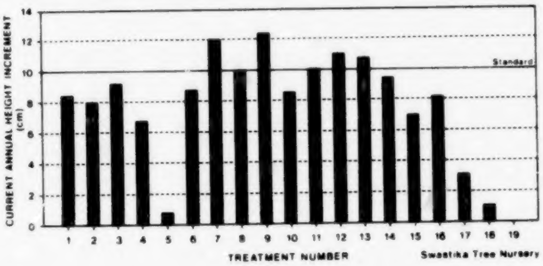

Figure 1. Careful Planting Trial 1987: current annual height increment, black spruce.

4) Conclusion

Table 1 shows that, with black spruce, we expect to have at least 10 cm of current annual height growth in the first year of planting. If we review the MacMillan data in Figure 1, we will see that only six of the 19 treatments, or approximately one-third, achieved the desired objective. How do the six treatments that reach the standard differ from the others? How do we improve the overall average and reduce the variability? Obviously, there is a great deal of work to be done.

AN INDUSTRY VIEWPOINT

M.F. Squires
Divisional Forester
Lakehead Woodlands Division
Abitibi-Price Inc.
Thunder Bay, Ontario

At the three Thunder Bay mills of Abitibi-Price Inc., our artificial regeneration objective is supply 714,000 m^3 of wood per year from the Spruce River Forest Management Agreement (FMA) alone.

Our net volume requirements are currently being met by the FMA, purchases and freehold supply. Over several decades, however, the availability of fiber from these sources will decrease, and our needs will have to be met by miscellaneous licences. By the year 2032 plantations will be maturing and, from then on, supply will return to the level set in our objective. Total supply will continue to be augmented by the purchase of roundwood and chips.

In addition to this long-term objective, we have set six specific goals:

1) to plant 4.7 million trees a year on 2,200 ha of the best sites
2) to produce trees that are 1 m tall at the fifth-year assessment
3) to ensure that trees achieve free-to-grow (FTG) status 10 years after planting
4) to produce 2,000 crop trees per ha at 10 years (i.e., when they have achieved FTG status)
5) to do commercial thinning at 30 years
6) to achieve a total merchantable volume of 210 m^3 per ha at the 50-year rotation.

Currently, we are not meeting our objective or our goals. As of 1987, we are approximately 4 million trees, or 1,800 ha, short of our planting goal. This goal was set in 1984 when we determined, with the best information available, what planting level would meet our objective.

In 1985 and 1986 the North Central Region container crops sustained substantial losses. Available planting stock did not meet our quality requirements, and therefore we were under target.

In the 1986-1991 five-year plan our goal of 4.7 million trees a year was approved. However, a cap of 3.8 million trees was placed on production for 1987, and it was recognized that the 1986 plant yielded only 3.6 million trees. That cap was close to the 3.6 million trees available for planting in 1986 after losses were tallied.

Plantations established in 1983 and 1984 generally appear to be meeting our goal of producing trees 1 m tall at the fifth-year assessment. In fact, some of the 1983 plantations have met this goal by year 4. The 1984 plantations will likely meet our goal in 1988.

Most of the stock we received in 1983 and 1984 exceeded our quality criteria.

Plantations established between 1985 and 1987 show variable growth, with only a few exhibiting the vigor of our 1983 and 1984 plantations. With the exception of snow-cached stock planted in 1987 in the Castle and Cook plantations, most of the stock was marginally acceptable.

Many of our 1983 and 1984 plantations already appear to meet the FTG criteria. Most can be expected to meet the criteria by the end of 1989. Some require tending.

Plantations established after 1984 may or may not achieve FTG status 10 years after planting. Many will have to increase their growth beyond current rates.

Stock received since 1984 has been of variable quality, and much has been marginal in relation to our specifications. The most notable exception was Castle and Cook stock snow-cached and planted in 1987.

All of our plantations, with a couple of exceptions, have achieved 90% survival; this should ensure approximately 2,000 crop trees per ha when FTG status has been achieved. With the addition of natural regeneration, density is currently between 2,200 and 2,300 seedlings of desirable species per ha in most areas.

In order to ensure that we meet our long-term objective and our goals, we should assume complete control of planting stock procurement. Direct contracts with private growers who will raise crops to our specifications appears to be the most secure route.

AN INDUSTRY VIEWPOINT

K.D. Virgo
Forestry Services Superintendent
Spruce Falls Power and Paper Company Ltd.
Kapuskasing, Ontario

How well are we meeting our artificial regeneration objectives?

Looking back about 10 years to the mid-1970s and comparing the situation then with the preseent situation, I would say that we have made tremendous progress. We have seen extensive growth in tree planting programs and the development of a whole new industry that did not exist six or seven years ago -- the production of containerized seedlings by private growers. We have seen improvements in the quality of stock as well, particularly container stock, although there are some exceptions. We have also seen improvements in the integration of harvesting and silviculture (e.g., on any one of a number of Forest Management Agreement (FMA) sites) which have enabled us to meet artificial regeneration objectives more efficiently. Last but not least, we have seen progress in the development of alternatives to tree planting.

There is a real need to maintain what I like to call "well balanced" regeneration programs, i.e., programs that take into consideration both site and economics, and that promote alternatives to costly and intensive tree planting on some sites and under some conditions. I do not believe that either the province of Ontario or the industry can afford to plant all of the area harvested or depleted through fire and/or insect infestation. I do not think that it is possible logistically, that it is necessary, or that it is even desirable.

Although planting programs are becoming larger and stock production is increasing, there is as much need as ever to pay attention to detail in the care of stock during the growing and planting phases. We have heard numerous times during this symposium about how stress can affect plantation performance. All of us involved in large planting and growing programs can recall occasions on which we got caught up in the "numbers game", and the consequent lack of attention to detail resulted in sloppy work and poor results. We cannot let our guard down; we must remain vigilant in the care of stock.

We have seen how poor communication can lead to major problems in stock production. For example, if we base seedling production, including growth parameters, on the capacity of existing nursery facilities, and impose quotas on stock production and specific stock types, regeneration may be inadequate.

At the Stock Production Development Activity Seminar held in December 1986 in Timmins, quality was defined as "fitness for purpose" (Sutton 1987), and this definition has been referred to frequently during the present symposium. My definition of quality, and that of my employer, Spruce Falls Power and Paper Company Ltd., is somewhat different. Quality, as we see it, is conformity to agreed-upon requirements. As managers of the Gordon Cosens Forest, using the best knowledge available to us at the time, we insist that, if we are to be held accountable for forest management, we be the ones to set the requirements. One could argue for years about what constitutes "fitness for purpose" without coming to a satisfactory conclusion.

We have made great strides in identifying what, in general, constitutes a quality tree as far as morphological characteristics are concerned, but we have just begun to develop tests for physiological characteristics. In my view, we have a long way to go before these tests will be of practical value for judging whether or not stock should be accepted.

What can we do to improve seedling production and care? For one thing, we can promote the idea of seedlings as living, immature, complicated organisms. Perhaps an appropriate poster placed on planting bags, container racks, delivery vans, etc., would aid in this effort. For another thing, we can and must renew our efforts to include attention to detail in the planning and implementation of stock growing and tree planting programs. The establishment of direct consumer/producer relationships between FMA holders and growers is a good move, and the direction in which we are headed, I believe. We must also develop cost-effective, practicable physiological testing so as to be in a better position to judge the physiological nature of stock quality. We must develop cold storage procedures further, dispense with artificially and arbitrarily imposed quotas on stock and, I believe, we should use plugs rather than containers when we plant seedlings. Paper should be an output of this process, not an input.

We have come a long way in our tree planting programs, but we still have a long way to go. We are somewhat like a rowboat full of people who have travelled halfway across the ocean: our objective is to get to the other side. On some days the breeze is at our backs, and we coast along in the desired direction without much effort. On other days it is stormy; the swells are really high and it looks as if we may sink at any minute. If we really want to get to the other side, we must pull together as a team. It is to be hoped that it will not take another disaster like Mount St. Helen's to make us realize this, and act accordingly.

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POSTER SESSIONS

THE PRESSURE BOMB AS A SILVICULTURAL TOOL

S.J. Colombo
Ontario Tree Improvement and Forest Biomass Institute
Ontario Ministry of Natural Resources
Maple, Ontario

Seedling desiccation during periods of drought after planting is a major cause of plantation failure. Proper handling techniques can help prevent water loss leading to high levels of plant moisture stress (PMS); however, techniques are needed to increase the ability of tree seedlings not only to survive but also to continue growth, even when PMS reaches high levels.

The ability of nursery stock to survive and grow during drought is determined on the basis of seedling water relations properties, which can be measured with a pressure bomb. The "wilting point" is one water relations property that can indicate a seedling's ability to withstand drought.

Seedling shoots are most drought-hardy when they have a high wilting point PMS. The wilting point drops rapidly from a maximum for dormant shoots to minimum values during shoot elongation, and increases again after bud initiation. Wilting point can be used to characterize the drought tolerance of nursery stock at time of shipping, and by use of a pressure bomb, field staff can determine whether nursery stock is at an acceptable PMS level.

Trials are being conducted to determine the amount of damage caused when trees of a known wilting point are exposed to given levels of PMS. In these trials the ability of seedlings to continue transpiration at increasing levels of PMS is determined through use of a porometer. At prescribed levels of PMS, stressed seedlings are rehydrated, potted and placed in a greenhouse. The recovery of transpiration and moisture stress is monitored and symptoms of desiccation damage are observed. It should be possible to predict the damage resulting from exposure to high PMS levels if the wilting point is known. Investigations are in progress to assess the effectiveness of cultural techniques in increasing the wilting point of seedlings, thereby improving the drought tolerance of nursery stock for plantation establishment.

TESTING PEAT QUALITY FOR CONTAINER SEEDLING PRODUCTION

R.S. Folk and V.R. Timmer
Faculty of Forestry
University of Toronto
Toronto, Ontario

Jack pine (*Pinus banksiana* Lamb.) seedlings were reared in Japanese paperpots filled with 26 different horticultural peats in quality tests for peat substrates. Diverse peat sources were selected to ensure a broad range of chemical and physical properties. Seedling growth and development varied on the different substrates; at harvest, there was a 52% difference in dry matter production between the best and poorest quality growing media. Seedling growth was weakly correlated with routine physical and chemical properties of the peats. Height growth was significantly related to nutrient composition of the seedlings, particularly N and P content, but correlations were low when tested against the nutrient status of the peats measured by conventional chemical tests. Leaching with liquid fertilizers revealed that the alkali-labile organic N in leachates was correlated strongly and inversely with seedling performance and N and P uptake, an indication that such compounds may be inhibitory to growth. A lettuce-seed bioassay with concentrated peat extracts demonstrated inhibitory effects, and was correlated significantly with jack pine growth. The fact that performance of the inferior was improved by increasing N fertilization suggests that inhibition may be associated with reduced availability of this nutrient. The significant correlation between soluble alkali-labile organic N in peat and seeding growth suggests that this measure may be a sensitive index of peat quality.

PLANTING STOCK QUALITY EVALUATION

C. Glerum
Ontario Tree Improvement and Forest Biomass Institute
Ontario Ministry of Natural Resources
Maple, Ontario

The quality of planting stock is measured with 1) morphological parameters such as height, diameter, oven-dry weight, root area or volume, needle length, bud size, and 2) physiological parameters such as root growth capacity, nutrient content, water relations, dormancy, frost hardiness, electrical impedance, food reserves and photosynthesis. The applicability of all these parameters is discussed within the framework of the planting stock quality concept that has, as its objective, the optimization of field performance (i.e., survival and growth).

INCREASING HEAT AND FROST TOLERANCE IN BLACK SPRUCE SEEDLINGS BY SHORT-DAY INDUCTION OF BUD INITIATION

R.S. Koppenaal and S.J. Colombo
Ontario Tree Improvement and Forest Biomass Institute
Ontario Ministry of Natural Resources
Maple, Ontario

Heat and frost can have a direct influence on post-planting seedling survival on open boreal sites. Operational testing and laboratory trials at the Ontario Tree Improvement and Forest Biomass Institute indicate that there is an increase in spruce *(Picea* spp.) seedling tolerance to high and low temperatures during the initial stages of bud development.

In comparison with an actively growing condition, 2 weeks of short photoperiod to induce bud initiation in overwintered 2-year-old container black spruce *(Picea mariana* [Mill.] B.S.P.) seedlings resulted in greater tolerance to high temperatures imposed in an environmental test chamber. At 42°C, almost half the length of the current shoots of actively growing seedlings was damaged, while bud-initiated seedlings were undamaged. Heat injury was also significantly reduced at 45°C and 50°C in bud-initiated seedlings.

Increased resistance to freezing damage at time of bud initiation has been observed in one-year-old black spruce seedlings in operational and experimental freezing tests. By means of the Index of Injury electrical conductivity technique, seedlings have been found to resist damage when exposed to a temperature of -15°C. In contrast, actively growing seedlings are damaged by exposure to temperatures between -5 and -7.5°C.

Two weeks of short photoperiod to initiate bud development in spruce may be a practicable means of conditioning seedlings to post-planting stresses and can be readily incorporated into operational greenhouse growing regimes.

THE EFFECT OF GREENHOUSE TEMPERATURES ON BUD INITIATION

K.D. Odlum and S.J. Colombo
Ontario Tree Improvement and Forest Biomass Institute
Ontario Ministry of Natural Resources
Maple, Ontario

The speed of bud initiation in seedlings of black spruce *(Picea mariana* [Mill.] B.S.P.) grown in the greenhouse can be greatly influenced by night-time temperatures. In a plant growth chamber study 12- to 14-week-old container-grown seedlings were exposed to a progressive shortening of daylengths simulating the natural daylength decline that occurs at 48°N, beginning on the first day of September. During this period of daylength decline the day temperature was maintained at 26°C while the night temperatures were 5, 7.5, 10, 14, 18, 22 or 26°C. Samples from each night temperature treatment were examined under a dissecting microscope twice a week for signs of bud initiation, first apparent as newly differentiated bud scales at the base of the terminal meristem. The time required for all seedlings within a treatment to initiate buds (100% bud initiation) varied as a result of night temperature. When the night temperature was 10°C to 22°C, 100% bud initiation was attained in 15 to 22 days; when the night temperature was 5, 7.5 or 26°C, 100% bud initiation was not attained until 40 days.

DECIDING WHEN AND WHAT TO PLANT? BE CAREFUL!

K.M. McClain
Northern Forest Research Unit
Ontario Ministry of Natural Resources
Thunder Bay, Ontario

Many silvicultural options, such as choice of species, stock type and time of planting, are available when reforestation projects are planned. Although every component of the regeneration plan is important to the ultimate success of a plantation, **when** and **what** to plant are often decided by default, the consequences of which rarely seem to be of concern. Research begun 11 years ago in an attempt to quantify differences in forest tree performance in relation to these factors has yielded results demanding that the questions of **when** and **what** to plant be given special consideration. In plantations established between 1975 and 1977, black spruce *(Picea mariana* [Mill.] B.S.P.) transplant and seedling nursery stock was planted at bi-weekly intervals throughout the frost-free season. Half of the nursery trees were spring-lifted and stored and the other half were fresh lifted prior to outplanting. The 11-year results from an exemplary plantation clearly show that **when** and **what** to plant are indeed important factors in determining plantation performance. For example, for plantings with more than 70% survival after 11 years, stem volumes varied by 218%, 370%, 62% and 80% for 1.5+1.5, 3+0, 1.5+.5 and 2+0 stock types, respectively. Other evidence suggests that these differences in volume production will widen with time. The practical implication of poor judgment on the issues of **when** and **what** to plant is obvious: at a fixed rotation age, volume will be reduced significantly; conversely, if trees are harvested when the desired volume is attained, the rotation will be lengthened.

STOCK PRODUCTION FOR PLANTATION PERFORMANCE

S.E. Parton and T.C. Huisman
Ontario Ministry of Natural Resources
Gogama, Ontario

Although all seedlings planted may meet or exceed current standards, variations in plantation performance do occur. The cultural practices used in the production of planting stock and its subsequent handling are thought to be largely responsible.

Two trial series were initiated in the Ontario Ministry of Natural Resources (OMNR) Northern Region to:

1) provide management information on early stock performance to enable calibration or adjustment of growing/planting systems

2) provide a common (defensible/verifiable) data base for discussion of stock standards.

The Careful Planting Trial Series and the Clients' Series Trial are a joint venture involving private growers, industry, research and OMNR personnel, coordinated by the Northern Forest Development Group (NFDG).

The two trial series will be conducted over 5 years and will involve both bare-root and container black spruce *(Picea mariana* [Mill.] B.S.P.) and jack pine *(Pinus banksiana* Lamb.). The Clients' Series Trial attempts to determine how various climatic and site conditions throughout the region interact with seedlings grown under various growing regimes. The Careful Planting Trial Series was established under semi-controlled conditions to reduce variations in site and handling so that seedling performance could be attributed to the quality of the stock as a result of cultural practices.

The information obtained from these two trials will then be combined to form a data base to provide sound biological information on planting stock and field performance. This will ensure that the most suitable stock is planted to achieve maximum site productivity.

GOOD PLANTING PAYS

J. Paterson and C. Glerum
Ontario Tree Improvement and Forest Biomass Institute
Ontario Ministry of Natural Resources
Maple, Ontario

The physical shock to the seedling at planting is one of the most critical factors in the establishment of a new stand. Planting quality has a direct effect on survival and growth (i.e., field performance) and will determine future forest management: **NO TREES - NO MANAGEMENT; SLOW ESTABLISHMENT = SLOW FUTURE GROWTH.** Good planting will help to ensure trees for the future.

In 1976 a research study was initiated to look at the effects of handling and planting on the field performance of 3+0 red pine *(Pinus resinosa* Ait.). Six Ontario Ministry of Natural Resources districts were involved in this study, in which 7,547 trees were compared. A description of this study and the first-, second- and fifth-year results of field performance have been reported in forest research notes 6, 14 and 29 (by Pierpoint et al.), which are available from the Ontario Tree Improvement and Forest Biomass Institute. The present poster outlines the 10-year results of this study.

In the tenth year, survival, total height and diameter at breast height were assessed and basal area per hectare was calculated. When the research plantings and operational plantings used at that time are compared and all districts are combined, striking differences are observed:

Losses incurred by operations

	Survival	Total ht	DBH	BA (m^2/ha)
Net loss (%)	26	6	9	27

The net loss in survival and diameter growth have contributed to an overall loss in basal area production of 27%. This loss may increase with time because of the slow establishment of the operationally planted trees.

Good planting does result in:

1) higher survival
2) faster growth rates
3) proper spacing for self pruning
4) lower costs for refilling
5) generally lower tending costs.

These, in turn, will result in higher productivity for a given area, shorter rotation age and an earlier return on one's initial investment.

The results of this study have already had an influence on present operational plantings, but with the increased production targets for planting stock there is the risk of reverting to past planting problems.

Reduced productivity, longer rotations and increased management costs to tend poorly developing plantations is unacceptable. We must therefore ensure **GOOD PLANTING QUALITY.**

MODELING FOREST REGENERATION IN ONTARIO: A PRELIMINARY REPORT

B. Payandeh
Government of Canada
Canadian Forestry Service
Great Lakes Forestry Centre
Sault Ste. Marie, Ontario

A management-oriented computer model entitled "PLANT" is being developed for Ontario's major timber species: black spruce *(Picea mariana* [Mill.] B.S.P.), white spruce *(P. glauca* [Moench] Voss) and jack pine *(Pinus banksiana* Lamb.). The entire regeneration process, i.e., from seed source selection to successful plantation establishment, is treated as three separate but interdependent phases of: 1) stock production, 2) storage, and 3) plantation management. During each phase, growth and survival of seedlings are simulated according to empirical submodels reflecting the effects of various biological factors as well as management options.

The model simulates various regeneration systems on the basis of a "decision tree" approach and the user's specifications. It compares, ranks and optimizes the alternatives so generated on the basis of an index combining the total cost of production, growth, survival and the quality of the resulting stands. It reports up to five of the best ranking alternatives, both in tabular and in graphical form, for the user's examination.

"STOCK" is a subset of the above model developed for use by nurserymen and private growers concerned with stock production. It simulates the early growth and survival of seedlings during the greenhouse/nursery phase of the regeneration process as they are affected by possible treatments. It compares ranks and optimizes various stock production methods on the basis of a cost efficiency index similar to that described above. Both models are user friendly and written in FORTRAN and APPLE BASIC, the latter being a fully menu-driven program.

OVERWINTERING AND FROZEN STORAGE OF CONTAINER AND BARE-ROOT NURSERY STOCK

G.D. Racey and S.J. Colombo
Ontario Tree Improvement and Forest Biomass Institute
Ontario Ministry of Natural Resources
Maple, Ontario

At present, most species of bare-root stock and all container stock in Ontario are overwintered out of doors. As a result, both types of nursery stock are susceptible to losses from winter desiccation and rodents, while bare-root stock also suffers from frost heaving and container stock from root freezing damage. Research results from Ontario show that properly conditioned, lifted, handled and frozen-stored nursery stock will survive and grow the following year as well as stock overwintered out of doors, while frozen storage offers the following additional benefits: 1) it provides stock for early shipment to planting sites when bare-root and container nursery stock are still frozen-in; 2) stock can be held dormant until planting-site conditions are favorable (e.g., not too cold, too dry or under bush restrictions); 3) spring labor shortages can be avoided and the workload can be extended; 4) an accurate inventory of available shipping stock can be made in the fall; and 5) double-crop production of spruce container stock can be rendered practicable because seedlings can go directly into storage from the greenhouse rather than out of doors.

STOCK PRODUCTION TRENDS AT SWASTIKA

E.M. Raitanen
Ontario Ministry of Natural Resources
Swastika Tree Nursery
Swastika, Ontario

The production of conventional bare-root stock is a challenging proposition. The nurseryman must be prepared to respond to challenges presented by the environment, new cultural practices and the needs of various client groups.

Over its 30-year history, Swastika has undergone many changes in stock production. The number of pine *(Pinus* spp.) seedlings grown, for example, has been greatly reduced. Transplant production has replaced seedling production in both black spruce *(Picea mariana* [Mill.] B.S.P.) and white spruce *(P. glauca* [Moench] Voss). Container production has been privatized and the greenhouses have been converted to accelerated transplant production.

Swastika has produced transplant stock of a fairly consistent size for a number of years. New initiatives in cultural practices under investigation at Swastika and other bare-root nurseries will provide the opportunity to manipulate growing schedules and improve stock quality.

Tree seedlings are living organisms. They cannot be produced and handled as if they were cans of beans or coat hangers. In tree seedling production, the physiological condition of the entire tree must be considered, as well as its morphological parameters. Morphological and physiological measurements for each stock type must be connected with subsequent plantation performance if realistic, achievable goals are to be set for the nurseryman. Above all, both clients and producers should keep the biology of the tree in mind and work together to guarantee the success of the reforestation effort.

COMPETITION CONTROL WITH PRONONE (GRANULAR HEXAZINONE) APPLIED IN WINTER

J.E. Wood and F.W. von Althen
Government of Canada
Canadian Forestry Service
Great Lakes Forestry Centre
Sault Ste. Marie, Ontario

and

R.A. Campbell
Pest Control Section
Ontario Ministry of Natural Resources
Maple, Ontario

Competition from herbaceous weeds and grasses is a serious problem in the reforestation of boreal mixedwood cutovers. The virgin stands of this forest type consist mainly of white spruce (*Picea glauca* [Moench] Voss), black spruce (*P. mariana* [Mill.] B.S.P.), trembling aspen (*Populus tremuloides* Michx.) and white birch (*Betula papyrifera* Marsh.). The soils are characterized by an organic layer, less than 30 cm deep, over well drained to moderately well drained, stone-free, fine loamy clays or silt loams. The most common method of site preparation is shearblading in winter. It consists of the removal of slash and stumps by bulldozer blade in corridors 4 m wide alternating with windrows of debris of the same width.

To determine the feasibility of winter application of herbicide, its effectiveness in competition control, and its effects on crop tree survival and growth, Pronone 5G and 10G (5% and 10% a.i.) was applied at 2 and 4 kg a.i./ha in February 1985 in shearbladed corridors. Black spruce 1+1 transplants and seedlings in FH508 Japanese paperpots were planted in June 1985 and 1+1 transplants and seedlings in FH408 paperpots were planted in July 1985.

Application of Pronone at both rates greatly reduced the density and vigor of the herbaceous competition and had no phytotoxic effects on the planted spruce. After two growing seasons survival was 96% or more for all planting stock except the FH408 paperpot seedlings planted in July in plots treated with 4 kg a.i./ha of Pronone 10G.

Second-year height increment of both stock types was significantly higher in the Pronone-treated plots that in the controls. The highest increment always occurred in the plots treated with 4 kg a.i./ha of Pronone. Season of planting had no effect on the height increment of the seedlings planted in paperpots, but summer planting greatly reduced the height increment of the transplants.

LIST OF PARTICIPANTS

Aidelbaum, A.S.
North Gro Development Ltd.
75 Government Road W.
Kirkland Lake, Ontario
P2N 2E6

Aidelbaum, M.
North Gro Development Ltd.
75 Government Road W.
Kirkland Lake, Ontario
P2N 2E6

Aiking, A.F.
Hilleshog Forestry AB
789 Don Mills Road
Suite 700
Toronto, Ontario
M3C 3L6

Altmann, B.
Ontario Ministry of Natural Resources
R.R.#2,
Kenora, Ontario
P9N 3W8

Ardron, G.
Manitoba Department of Natural Resources
Forestry Branch
300-520 Kenaston Blvd
Winnipeg, Manitoba
R3N 1Z4

Armson, K.A.
Ontario Ministry of Natural Resources
Room 6520, Whitney Block
99 Wellesley Street West
Toronto, Ontario
M7A 1W3

Atkins, R.C.
Ontario Ministry of Natural Resources
P.O. Box 129
Swastika, Ontario
P0K 1T0

Atkinson, J.B.
Manitoba Department of Natural Resources
Pineland Provincial Forest Nursery
P.O. Box 45
Hadashville, Manitoba
R0E 0X0

Aubichon, S.M.
Ontario Paper Co.
P.O. Box 700
Hornepayne, Ontario
P0M 1Z0

Baars, C.T.
Jiffy Products NB Ltd
1125 Stephenson Drive
Burlington, Ontario
L7S 1Y8

Baker, W.D.
Ontario Ministry of Natural Resources
Orono Forest Station
P.O. Box 119
Orono, Ontario
L0B 1M0

Bemister, D.
Ontario Ministry of Natural Resources
190 Cherry St.
Chapleau, Ontario
P0M 1K0

Bidwell, P.
Ontario Ministry of Natural Resources
6-8-10 Government Road
Kapuskasing, Ontario
P5N 2W4

Billings, R.
Ontario Ministry of Natural Resources
190 Cherry Street
Chapleau, Ontario
P0M 1K0

Blazecka, J.S.
Blazecka's Greenhouses Inc.
R.R.#2
Cochrane, Ontario
P0L 1C0

Bolduc, V.J. and A.J.
North Shore Nursery
R.R.# 1
Bruce Mines, Ontario
P0R 1C0

Bons, E.
Ontario Ministry of Natural Resources
Thunder Bay Office
435 S. James Street
P.O. Box 5000
Thunder Bay, Ontario
P7C 5G6

Booth, R.
Domtar Inc.
Forest Products Division
P.O. Box 480
Red Rock, Ontario
P0T 2P0

Boothe, D.E.
Lava Mountain Ltd.
P.O. Box 10
Ramore, Ontario
POK 1RO

Borowski, P.
Manitoba Department of Natural Resources
P.O. Box 10
27-2nd Ave. S. W.
Dauphin, Manitoba
R7N 3E5

Bourque, P.P.
Ropak Can-Am Ltd.
P.O. Box 340
Springhill, Nova Scotia
BOM 1XO

Boysen, E.
Ontario Ministry of Natural Resources
10 Findlay Ave.
Carleton Place, Ontario
K7C 3Z6

Burger, D.H.
Superior Forest Management Ltd.
P.O. Box 1323
10 Young Street
Chapleau, Ontario
POM 1KO

Burgess, D.
Canadian Forestry Service
Petawawa National Forestry Institute
Chalk River, Ontario
KOJ 1JO

Burnside, N.E.
Ontario Ministry of Natural Resources
P.O. Box 310
Thessalon, Ontario
POR 1LO

Campbell, A.U.
Ontario Ministry of Natural Resources
R.R.#4
Kemptville, Ontario
KOG 1JO

Campbell, M.
Ontario Ministry of Natural Resources
Dryden Tree Nursery
P.O. Box 90
Wabigoon, Ontario
POV 2WO

Canning, B.R.
Canadian Forestry Service
Great Lakes Forestry Centre
P.O. Box 490
Sault Ste. Marie, Ontario
P6A 5M7

Cantin, J.M.
Levesque Lumber
P.O. Box 460
Hearst, Ontario
POL 1NO

Carl, N.J.
Great Lakes Forest Products
P.O. Box 430
Thunder Bay, Ontario
P7C 4W3

Carleton, J.
Ontario Ministry of Natural Resources
190 Cherry Street
Chapleau, Ontario
POM 1KO

Carlson, O.R.
Ontario Ministry of Natural Resources
108 Saturn Ave.
Atikokan, Ontario
POT 1CO

Cary, J.R.
Ontario Ministry of Natural Resources
3rd floor, Whitney Block
Queen's Park
Toronto, Ontario
M7A 1W3

Cassidy, B.A.
Ontario Ministry of Natural Resources
P.O. Box 129
Swastika, Ontario
POK 1TO

Chapeskie, D.J.
Ontario Ministry of Natural Resources
P.O. Box 605
Brockville, Ontario
K6V 5Y8

Citro, A.C.
Ontario Ministry of Natural Resources
Room 3633, Whitney Block
Queen's Park
Toronto, Ontario
M7A 1N3

Clarkson, P.D.
Technical Forestry Service Ltd.
141-5th Street S.E.
Portage Laprairie, Manitoba
R1N 1H4

Cloutier, J.
Service canadien des forêts
1574 Chemin Sullivan
Val D'Or, Quebec
G1S 2L2

Coles, J.F.
Ontario Tree Improvement Council
Johnston Hall
University of Guelph
Guelph, Ontario
N1G 2W1

Collins, W.H.
Algonquin College
315 Pembroke St. E.
Pembroke, Ontario
K8A 3K2

Colombo, S.J.
Ontario Ministry of Natural Resources
Ontario Tree Improvement and
Forest Biomass Institute
Maple, Ontario
L0J 1E0

Corbeil, P.
WaferBoard Corp.
Timmins, Ontario
P4N 7J3

Corbett, B.
Canadian Forestry Service
Petawawa National Forestry Institute
Chalk River, Ontario
K0J 1P0

Craig, G.D.
Ontario Ministry of Natural Resources
Red Lake District Office
P.O. Box 5003
Red Lake, Ontario
P0V 2M0

Croisier, M.
Aidie Creek Gardens Inc.
R.R.#3
Englehart, Ontario
P0J 1H0

Daigle, G.A.
Ontario Ministry of Natural Resources
P.O. Box 670
Hearst, Ontario
P0L 1N0

Daoust, A.L.
Centre de foresterie des Laurentides
Service canadien des forêts
C.P. 3800
1055 Rue du Peps
Ste-Foy, Quebec
G1V 4C7

Davison, R.W.
Ontario Ministry of Natural Resources
P.O. Box 309
Manitouwadge, Ontario
P0T 2C0

Dawes, R.M.
Evergreen Farms
48 Princess Street
Dryden, Ontario
P8N 1C7

Day, R.J.
School of Forestry
Lakehead University
Thunder Bay, Ontario
P7E 5E1

deWitt, J.
Northern Clonal Forestry Centre
P.O. Box 150
Moonbeam, Ontario
P0L 1V0

De Yoe, D.
MacMillan Bloedel Ltd.
65 Front Street
Nanaimo, British Columbia
V9R 5H9

Dolhy, T.W.
Ontario Ministry of Natural Resources
P.O. Box 129
Swastika, Ontario
P0R 1T0

Dorie, M.
Ontario Ministry of Natural Resources
190 Cherry Street
Chapleau, Ontario
P0M 1K0

Dunn, S.M.
Millson Forestry Service
1782 Dalton Road
R.R.#1
Timmins, Ontario
P4N 7C2

Eddy, A.J.
Canadian Forestry Service
P.O. Box 667
Truro, Nova Scotia
B2N 5E5

Edmonds, R.
McChesney Lumber E.B. Eddy
P.O. Box 150
Timmins, Ontario
P4N 7C9

Edwards, I.K.
Canadian Forestry Service
Northern Forestry Centre
5320-122nd Street
Edmonton, Alberta
T6H 3S5

Emery, R.
Brinkman & Associates Reforestation Ltd.
6151 Thorne Ave.
Burnaby, British Columbia
V3N 2T8

Farrell, J.J.
Canadian Forestry Service
Great Lakes Forestry Centre
P.O. Box 490
Sault Ste. Marie, Ontario
P6A 5M7

Fautley, R.
Canadian Forestry Service
101-15th Street
Prince Albert, Saskatchewan
S6V 1G1

Filion, R.
Northern Clonal Forestry Centre
P.O. Box 150
Moonbeam, Ontario
POL 1V0

Fiset, L.
Liskeard Lumber
P.O. Box 595
New Liskeard, Ontario
POJ 1P0

Ford, R.D.
Ontario Ministry of Natural Resources
P.O. Box 129
Swastika, Ontario
POK 1T0

Fox, J.E.
Birchill Nurseries Inc.
Box 22, Site 9, R.R.#2
Cochrane, Ontario
POL 1C0

Galloway, R.L.
Ontario Ministry of Natural Resources
60 Wilson Ave.
Timmins, Ontario
P4N 2S7

Gemmell, R.G.
Abitibi-Price Inc.
P.O. Box 550
Iroquois Falls, Ontario
POK 1E0

Gerber, K.
Ontario Ministry of Natural Resources
P.O. Box 129
Swastika, Ontario
POK 1T0

Girouard, R.M.
Centre de foresterie des Laurentides
Service canadien des forêts
C.P. 3800
1055 Rue du Peps
Ste-Foy, Quebec
G1V 4C7

Glerum, C.
Ontario Ministry of Natural Resources
Ontario Tree Improvement and
Forest Biomass Institute
Maple, Ontario
LOJ 1E0

Goulet, S.
M. Kean Resources Inc.
P.O. Box 2120
Timmins, Ontario
P4N 7X8

Greenwood, R.B.
Ontario Ministry of Natural Resources
60 Wilson Ave.
Timmins, Ontario
P4N 2S7

Greet, R.M.
Canadian Forestry Service
Great Lakes Forestry Centre
P.O. Box 490
Sault Ste. Marie, Ontario
P6A 5M7

Grossnickle, S.J.
Forest Biotechnology Centre
B.C. Research
3650 Westbrook Mall
Vancouver, B.C.
V6S 2L2

Grundy, E.
Grundy's Nurseries
Pass Lake, Ontario
POT 2M0

Gower, W.G.
Ontario Ministry of Natural Resources
Gogama District Office
P.O. Box 129
Gogama, Ontario
POM 1W0

Haig, R.A.
Canadian Forestry Service
Great Lakes Forestry Centre
P.O. Box 490
Sault Ste. Marie, Ontario
P6A 5M7

Hall, J.P.
Canadian Forestry Service
351 Boulevard St. Joseph
Hull, Quebec
K1A 1G5

Heaman, D.K.
Ontario Ministry of Natural Resources
199 Larch Street
Sudbury, Ontario
P3E 5P9

Heikurinen, J.K.
Ontario Ministry of Natural Resources
199 Larch Street
Sudbury, Ontario
P3E 5P9

Hicks, G.L.
Wellair Concepts Inc.
Gold Pine Nursery
P.O. Box 339
Ear Falls, Ontario
POV 1T0

Hills, C.
Somerville Nurseries Ltd.
P.O. Box 70
Alliston, Ontario
L0M 1A0

Hodgson, T.J.
Beaver Plastics
12150-160 St.
Edmonton, Alberta
T5V 1H5

Huisman, T.
Ontario Ministry of Natural Resources
P.O. Box 129
Gogama, Ontario
POM 1W0

Hutchison, R.E.
Ontario Ministry of Natural Resources
Midhurst Research Unit
Midhurst, Ontario
L0L 1X0

Iles, V.
Ontario Ministry of Natural Resources
6-8-10 Government Road
Kapuskasing, Ontario
P5N 2W4

James, B.E.
Ontario Ministry of Natural Resources
P.O. Box 309
Manitouwadge, Ontario
POT 2C0

Jovic, D.
Ontario Ministry of Natural Resources
P.O. Box 640
Geraldton, Ontario
POT 1M0

Juzwik, J.
Ontario Ministry of Natural Resources
Pest Control Section
10401 Dufferin Street
Maple, Ontario
L0J 1E0

Kean, M.C.
M. Kean Resources Inc.
P.O. Box 2120
Timmins, Ontario
P4N 7X8

Keane, R.K.
Ontario Ministry of Natural Resources
P.O. Box 605
Brockville, Ontario
K6V 5Y8

Kekanovich, J.
Ontario Ministry of Natural Resources
60 Wilson Ave.
Timmins, Ontario
P4N 2S7

Kennington, D.J.
Canadian Forestry Service
Great Lakes Forestry Centre
P.O. Box 490
Sault Ste. Marie, Ontario
P6A 5M7

Kershaw, H.M.
Ontario Ministry of Natural Resources
199 Larch Street
Sudbury, Ontario
P3E 5P9

Kilgour, M.
Ontario Ministry of Natural Resources
896 Riverside Drive
Timmins, Ontario
P4N 3W2

Kimmett, C.R.
Sir Sandford Fleming College
P.O. Box 8000
Lindsay, Ontario
K9V 5E6

Kirkland, C.
Ontario Ministry of Natural Resources
P.O. Box 670
Hearst, Ontario
POL 1NO

Klapprat, R.A.
Ontario Ministry of Natural Resources
R.R.# 1
Thunder Bay, Ontario
P7C 4T9

Koppenaal, R.S.
Ontario Ministry of Natural Resources
Ontario Tree Improvement and
Forest Biomass Institute
Maple, Ontario
LOJ 1EO

Krygier, R.F.
Domtar Forest Products
White River Division
P.O. Box 2000
White River, Ontario
POM 3GO

Ladouceur, M.
Levesque Lumber
P.O. Box 460
Hearst, Ontario
POL 1NO

Lafleur, G.
Lafleur Gardens Ltd.
Airport Road
Timmins, Ontario
P4N 7C3

Laganiere, M.
IPL Inc.
140 Commerciale
St-Damien, Quebec
GOR 2YO

Lambert, L.
Ontario Ministry of Natural Resources
Room 3646, Whitney Block
Queen's Park
Toronto, Ontario
M7A 1W3

Lambert, R.
Ontario Ministry of Natural Resources
60 Wilson Avenue
Timmins, Ontario
P4N 2S7

Lamy, M.G.
La Maison Verte
P.O. Box 1868
Hearst, Ontario
POL 1NO

Lanigan, M.E.
Superior Forest Management Ltd.
P.O. Box 1323
10 Young Street
Chapleau, Ontario
POM 1KO

Lecours, Y.M.
Lecours Lumber Co. Ltd.
P.O. Box 9000
Hearst, Ontario
POL 1NO

Lee, G.
Spruce Falls Power & Paper Co. Ltd.
P.O. Box 100
Kapuskasing, Ontario
P5N 2Y2

Lemaistre, G.
Boise-Cascade Canada Ltd.
Woodland Division
P.O. Box 5000
435 S. James Street
Thunder Bay, Ontario
P7C 5G6

Levangie, G.M.
Energreen Enterprises Inc.
P.O. Box 329
Swastika, Ontario
POK 1TO

Liddle, Gerry T.
Aquanorth Farms Inc.
P.O. Box 390
North Bay, Ontario
P1B 8H9

Linehan, B.
Strathlorne Nursery
P.O. Box 489
Inverness, Nova Scotia
BOE 1NO

MacDonald, C.
Superintendant
Pine Ridge Forest Nursery
P.O. Box 750
Smokey Lake, Alberta
TOE 3CO

MacIver, D.
Department of the Environment
Atmospheric Environment Service
4905 Dufferin Street
Downsview, Ontario
M3H 5T4

Maclean, H.
Ontario Ministry of Natural Resources
6-8-10 Government Road
Kapuskasing, Ontario
P5N 2W4

Marsh, C.
Ontario Ministry of Natural Resources
808 Robertson Street
Kenora, Ontario
P9N 3X9

Mason, C.
Ontario Ministry of Natural Resources
P.O. Box 670
Hearst, Ontario
POL 1NO

Mathews, A.G.
Boise-Cascade Canada Ltd.
1455 Idylwild Drive
Fort Frances, Ontario
P9A 3M3

McClain, K.M.
Ontario Ministry of Natural Resources
Ontario Tree Improvement and
Forest Biomass Institute
P.O. Box 2960
Thunder Bay, Ontario
P7B 5G5

McHale, D.E.
Ontario Ministry of Natural Resources
896 Riverside Drive
Timmins, Ontario
P4N 3W2

McLeod, G.R.
Ontario Ministry of Natural Resources
Orono Forest Station
P.O. Box 119
Orono, Ontario
LOB 1MO

McQueen, J.
Canadian Forestry Service
104-180 Main Street
Winnipeg, Manitoba
R3C 1A6

Miller, I.
Canadian Forestry Service
Petawawa National Forestry Institute
Chalk River, Ontario
KOJ 1JO

Miller, J.S.
Ontario Ministry of Natural Resources
896 Riverside Drive
Timmins, Ontario
P4N 3W2

Mills, W.
Northern Forestry Centre
Canadian Forestry Service
5320-122nd Street
Edmonton, Alberta
T6H 3S5

Millson, S.V.
Millson Forestry Service
1782 Dalton Road
R.R.# 1
Timmins, Ontario
P4N 7C2

Momy, S.
Northern Greenhouse Farms
273 Third Avenue, Suite 402
Timmins, Ontario
P4N 1E2

Morrison, R.
Ontario Ministry of Natural Resources
P.O. Box 129
Swastika, Ontario
P0K 1T0

Moryto, W.N.
Ontario Ministry of Natural Resources
P.O. Box 129
Gogama, Ontario
P0M 1W0

Nakamura, W.
Ontario Ministry of Natural Resources
P.O. Box 5000
435 S. James Street
Thunder Bay, Ontario
P7C 5G6

Neil, J.
Jellien Nurseries Armstrong Ltd.
P.O. Box 142
Armstrong, Ontario
P0T 1A0

Nicks, B.D.
E.B. Eddy Forest Products Ltd.
1 Station Road
Espanola, Ontario
P0P 1C0

Odlum, K.D.
Ontario Ministry of Natural Resources
Ontario Tree Improvement and
Forest Biomass Institute
Maple, Ontario
L0J 1E0

Oldford, G.C.
Ontario Ministry of Natural Resources
896 Riverside Drive
Timmins, Ontario
P4N 3W2

Oleynik, J.M.
Dubreuil Brothers Ltd.
Dubreuilville, Ontario
P0S 1B0

O'Neill, G.J.
Ontario Ministry of Natural Resources
R.R.#1 Midhurst
Midhurst, Ontario
L0L 1X0

Park, T.D.
Ontario Ministry of Natural Resources
P.O. Box 5003
Red Lake, Ontario
P0V 2M0

Parton, S.E.
Ontario Ministry of Natural Resources
P.O. Box 129
Gogama, Ontario
P0M 1W0

Paterson, J.M.
Ontario Ministry of Natural Resources
Ontario Tree Improvement and
Forest Biomass Institute
Maple, Ontario
L0J 1E0

Payandeh, B.
Canadian Forestry Service
Great Lakes Forestry Centre
P.O. Box 490
Sault Ste. Marie, Ontario
P6A 5M7

Peacock, T.H.
Abitibi-Price Inc. Woodlands
P.O. Box 10
Pine Falls, Manitoba
R0E 1M0

Pinkerton, C.
Liskeard Lumber
P.O. Box 595
New Liskeard, Ontario
P0J 1P0

Pinto, F.
Ontario Ministry of Natural Resources
P.O. Box 129
Gogama, Ontario
P0M 1W0

Polhill, B.E.
Ontario Ministry of Natural Resources
Dryden Tree Nursery
P.O. Box 90
Wabigoon, Ontario
POV 2W0

Preiss, S.W.
McChesney Lumber E.B. Eddy
P.O. Box 150
Timmins, Ontario
P4N 7C9

Price, S.
Canadian Forestry Service
Northern Forestry Centre
5320-122nd Street
Edmonton, Alberta
T6H 3S5

Prince, F.A. Jr.
37069 Charter Oaks Blvd
Mount Clemens, Michigan
48043

Pullen, J.
University of Guelph
Environmental Biology
Crop Science Building
Room 419
Guelph, Ontario
N1G 2W1

Racey, G.
Ontario Ministry of Natural Resources
Midhurst Research Unit
Midhurst, Ontario
LOL 1X0

Radford, M.J.
Ontario Ministry of Natural Resources
P.O. Box 129
Swastika, Ontario
POR 1T0

Raitanen, W.E.
Ontario Ministry of Natural Resources
60 Wilson Avenue
Timmins, Ontario
P4N 2S7

Rauter, R.M.
Ontario Forest Industries Association
130 Adelaide Street West
Toronto, Ontario
M5H 3P5

Reese, K.H.
Ontario Ministry of Natural Resources
Forest Tree Nursery
Midhurst, Ontario
LOL 1X0

Reffle, R.J.
Ontario Ministry of Natural Resources
Whitney Block, Room 3655
99 Wellesley Street West
Toronto, Ontario
M7A 1W3

Reid, J.
Ontario Ministry of Natural Resources
435 S. James Street
Thunder Bay, Ontario
P7C 5G6

Riley, L.F.
Canadian Forestry Service
Great Lakes Forestry Centre
P.O. Box 490
Sault Ste. Marie, Ontario
P6A 5M7

Ritchie, G.A.
Centralia Research Center
Weyerhaeuser Company
505 Pearl Street
Centralia, Washington
98531

Rogers, D.
Ontario Ministry of Natural Resources
60 Wilson Avenue
Timmins, Ontario
P4N 2S7

Ross, P.A.
New North Greenhouses
P.O. Box 1267
Sault Ste. Marie, Ontario
P6A 6N1

Roy, D.S.
Cochrane Enterprise
P.O. Box 1059
Cochrane, Ontario
POL 1C0

Russell, J.
Ontario Paper Company
P.O. Box 1210
South Porcupine, Ontario
PON 1H0

Salonius, P.O.
Canadian Forestry Service
CFS-Maritimes
P.O. Box 4000
Fredericton, New Brunswick
E3B 5P7

Scarratt, J.B.
Canadian Forestry Service
Great Lakes Forestry Centre
P.O. Box 490
Sault Ste. Marie, Ontario
P6A 5M7

Sherwin, R.
Ontario Ministry of Natural Resources
Thunder Bay Forest Nursery
R.R.# 1
Thunder Bay, Ontario
P7C 4T9

Skidmore, G.R.
Birchill Nurseries Inc.
Box 22, Site 9, R.R.#2
Cochrane, Ontario
POL 1C0

Skidmore, R.
Birchill Nurseries Inc.
Box 22, Site 9, R.R.#2
Cochrane, Ontario
POL 1C0

Smith, C.R.
Canadian Forestry Service
Great Lakes Forestry Centre
P.O. Box 490
Sault Ste. Marie, Ontario
P6A 5M7

Smith, G.K.M.
Canadian Forestry Service
Great Lakes Forestry Centre
P.O. Box 490
Sault Ste. Marie, Ontario
P6A 5M7

Smith, W.
Way Da Gro Forestry Services
231 Greenhill Ave.
North Bay, Ontario
P1C 1J1

Spence, R.J.
Ontario Ministry of Natural Resources
Metcalfe Street
Tweed, Ontario
K0K 3J0

Squires, M.F.
Abitibi-Price Lakehead Woodlands
P.O. Box 2510
Thunder Bay, Ontario
P7B 5E9

Stanclik, G.E.
Abitibi-Price Inc.
P.O. Box 550
Iroquois Falls, Ontario
P0K 1E0

Stillar, D.A.
Ontario Ministry of Natural Resources
P.O. Box 730
Cochrane, Ontario
P0L 1C0

Stjernberg, E.I.
FERIC
143 Place Frontenac
Pointe Claire, Quebec
H9R 4Z7

Sutton, R.F.
Canadian Forestry Service
Great Lakes Forestry Centre
P.O. Box 490
Sault Ste. Marie, Ontario
P6A 5M7

Stratton, D.
Spruce Falls Power & Paper Co. Ltd
P.O. Box 100
Kapuskasing, Ontario
P5N 2Y2

Taylor, R.W.
Ontario Ministry of Natural Resources
922 Scott Street
Fort Frances, Ontario
P9A 1J4

Thompson, J.
Department of Parks, Recreation and Culture
Forestry Branch
P.O. Box 3003
Prince Albert, Saskatchewan
S6V 6G1

Timmer, V.R.
University of Toronto
Faculty of Forestry
Toronto, Ontario
M5S 1A1

Tornblom, S.
Clearwater Provincial Forest Nursery
P.O. Box 2550
The Pas, Manitoba
R9A 1M4

Tower, A.M.
Hill Greenhouses Ltd.
R.R.#1
Murillo, Ontario
POT 2G0

Van Damme, L.W.
KBM Forestry Consultants Inc.
360 Mooney Street
Thunder Bay, Ontario
P7B 5R4

Van Duyn, H.
Hill Greenhouses Ltd.
R.R.#1
Murillo, Ontario
POT 2G0

Verheggen, F.J.
Ontario Ministry of Natural Resources
P.O. Box 640
Geraldton, Ontario
POT 1M0

Virgo, K.D.
Spruce Falls Power & Paper Co. Ltd.
P.O. Box 100
Kapuskasing, Ontario
P5N 2Y2

Virkkunen, M.
Hakmet Ltd.
881 Boulevard Harwood
P.O. Box 248
Dorion, Quebec
J7V 7J5

Warner, C.A.
Aidie Creek Gardens
R.R.#3
Englehart, Ontario
POJ 1H0

Weldon, T.
Canadian Forestry Service
Great Lakes Forestry Centre
P.O. Box 490
Sault Ste. Marie, Ontario
P6A 5M7

Whyte, G.
Ontario Ministry of Natural Resources
Dryden Tree Nursery
P.O. Box 90
Wabigoon, Ontario
POV 2W0

Wiensczyk, A.M.
Lakehead University
School of Forestry
Thunder Bay, Ontario
P7E 5E1

Wiggins, G.
University of Toronto
Faculty of Forestry
Toronto, Ontario
M5S 1A1

Wild, J.M.
Ontario Ministry of Natural Resources
199 Larch Street
Sudbury, Ontario
P3E 5P9

Willcocks, A.
Ontario Ministry of Natural Resources
435 S. James Street
Thunder Bay, Ontario
P7C 5G6

Williams, S.A.
Ontario Ministry of Natural Resources
P.O. Box 730
Cochrane, Ontario
POL 1C0

Wood, J.E.
Canadian Forestry Service
Great Lakes Forestry Centre
P.O. Box 490
Sault Ste. Marie, Ontario
P6A 5M7

Zdrazil, Z.
Canadian Forestry Service
Petawawa National Forestry Institute
Chalk River, Ontario
KOJ 1P0

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